AC 2009-1228: CONTENT IN CAPSTONE DESIGN COURSES: PILOT SURVEY RESULTS FROM FACULTY, STUDENTS, AND INDUSTRY

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Content in Capstone Design Courses:
Pilot Survey Results from Faculty, Students, and Industry

Abstract

Capstone design courses are a common culminating experience in engineering programs across the country. A pilot study was developed to probe the *content* included in capstone design courses. The study was motivated by a desire to understand not only what is taught in capstone courses, but how that content is covered, how well students think they have learned the content, what content proficiency is expected of entry level employees, and how important the content is for student learning from the perspective of faculty, students, and industry employers. The study consisted of three surveys (one for each of faculty, students, and industry) about a specific set of 24 capstone course topics. Responses were received from 48 faculty, 240 students, and 19 industry employees, representing five engineering disciplines. As a first look at a large set of results, this paper addresses the importance of the topics from the perspective of all three groups (faculty, students, industry) and presents data regarding what content faculty cover, methods of content delivery, reported student proficiency, and industry expectations for entry level employees. While the pilot study data are vast and multi-faceted, two emerging themes from all three surveys are a) the importance of professional skills for student learning and development and b) the disconnect between perceived and expected proficiency for capstone graduates. This effort adds to a growing body of work to understand and ultimately improve capstone education.

1. Introduction and Motivation

Capstone engineering design course program instantiations are based upon academic institution, department, and instructor. Each brings a unique perspective to the course and the learning environment. Capstone engineering design projects are each unique in their own right since individuals or teams may select a project that has never been done before. In this context of variations of uniqueness, if that can be used as a means to define an educational environment, is it possible to evaluate a capstone engineering design program, identify a benchmark, and recommend areas for improvement? The work presented in this paper is a first step in a longer process to answer this question.

The research discussed below builds on the premise that an academic institution is preparing its engineering students for a level of proficiency in their discipline. Upon graduation, these educated engineers are attractive to industry as entry-level employees. (Note, this work is specifically focused on the industrial career path.) The best measurement for proficiency is to validate industry's expectations of an entry-level engineer against the product that academia has produced. Within that context, the focus of this research is on the design, project, and professional attributes associated with *capstone* engineering courses.

The long-term motivation for this research is to identify and develop pedagogical methods to improve the proficiency of engineering students completing a capstone engineering design program, specifically, to make them more innovative, entrepreneurial, and able to meet the needs of their future careers. Additionally, the essential objective is to determine the best practices over the long term that improve the design proficiency of engineering students so that institutions can graduate students who are productive, highly skilled, and exceed performance expectations.

The philosophy in conducting this research was to develop and implement a broad-brush pilot survey of faculty/students/industry and then use the pilot data collected from academia and industry to guide a more focused study. In particular, the pilot survey focused on what/how content is taught in capstone courses, the importance of the content from the perspective of faculty students, and industry, and perceived and expected levels of proficiency with the content. This paper provides a broad review of the extensive pilot data, with initial discussions of the findings and suggestions for future work.

2. Survey Respondents and Methods

The pilot survey focus was to obtain information from academic engineering departments and industries that employed a dominant engineering discipline. The engineering disciplines considered in this pilot included chemical, civil, electrical, mechanical, and general engineering. An invitation to participate in the pilot study was sent in advance to faculty representing these departments at a selected set of 30 institutions; the list drew from institutions represented at the 2007 National Capstone Conference, randomly chosen across a range of Carnegie classifications[1]. Faculty members were also asked to forward the student survey to their students. A similar invitation to participate was made to 35 industry representatives. The companies were across industry sectors representing commercial, industrial, and military product and services, e.g., automation, computer, construction, financial, medical device, software, transportation, and utilities. Contact was made either through the technical and manufacturing departments or via human resources. An incentive of a first look, prior to publication, of the survey results was made to all companies who were solicited.

To inform the survey design, we reviewed related studies of proficiency and expectations.[2-5] We also consulted the literature to identify the critical skills and attributes necessary for design, project, and related engineering tasks[6-12] as well as topics covered in capstone courses as reported in previous surveys[13-14]. Further, since most engineering design is distributed over many different individuals, techniques, perspectives, decisions, and disciplines we reviewed the literature for the professional skills that allow for more effective and efficient interpersonal and collegial interactions.[15-22] While the objective was design proficiency, the development of professional skills to accomplish design is a necessity. The attributes considered in this pilot survey were drawn from a project development process: the ability to define the project, conceptualize, plan the project, work within and without a team environment, make decisions, formulate ideas, inform, persuade, inspire, estimate the risks, access the failure modes, validate and verify, design for X (e.g., assembly, manufacture, and environment), and deliver a quality outcome the meets or exceeds the sponsor or customer's expectations.

A manageable number of survey questions limited the inclusion of high number of candidate topics. The final selection of 24 topics in four categories, shown in Table 1, was culled from a list of nearly 100 areas of interest; the topics map to four main themes: problem definition, design, shared collaboration, and leadership. The selected topics were not intended to be allinclusive for the survey was a pilot effort; the topics were chosen to represent the broad nature of design proficiency, to enable identification of common ground and discrepancies, and to inform more in-depth subsequent research. A glossary for the selected topics is found in Appendix A. Note: Table 1 also lists the short topic name for each of the topics; the following presentation and discussion of the survey results refers to the topics by their short name.

Table 1 – Pilot Survey Topics

Category	Full Topic Name	Short Topic Name
Problem Definition	Need recognition	Need recognition
	Project framing/scoping	Problem framing
	Stakeholder objectives	Stakeholder objectives
	Technical design specifications	Design specifications
Design	Concept selection	Concept selection
	Creation/construction/fabrication/simulation	Fabrication/simulation
	Design for X (DFX)	Design for X
	Design refinement/iteration	Iteration
	Engineering economics	Engineering economics
	Project/design management	Project management
	Risk/failure mode effects analysis	Risk analysis
	Synthesis/embodiment design	Embodiment design
	Usability	Usability
	Verification and validation	Validation
Shared Collaboration	Active listening, hearing, and understanding	Active listening
	Initiative/ability to act	Initiative
	Multi-modal communication	Communication
	Networking	Networking
	Professional citizenship	Professional citizenship
Leadership	Coaching/mentoring	Coaching
	Commitment and trust	Commitment
	Delegation	Delegation
	Handling feedback/constructive criticism	Handling feedback
	Resource management	Resource management

Building on the topics above, we developed the pilot survey to gather data regarding the proficiency reached in academia (faculty and students), the desired level required by industry, and the gap between the two. We prepared three surveys, one for each of faculty, students, and industry respondents, and submitted for (and received) IRB approval. After an introductory page that queried respondent department and institutional affiliation (faculty and students) or engineering disciplines (industry), each survey included three main sections, as detailed in Appendix B. Note that for all but the open-ended response sections, respondents were presented with the list of 24 topics shown in Table 1. The topics were arranged in alphabetical order, were not divided by category, and were linked to a glossary of topic definitions (Appendix A). For those questions that survey respondents were required to answer in order to proceed to the next part of the survey, respondents always had the option of "N/A" if they did not know or chose not to answer.

The three surveys were implemented using SurveyMonkey; links were sent to all faculty and industry parties who accepted the initial invitation. Responses were received from 48 faculty (in 37 departments at 23 institutions), 240 students (in 34 departments at 21 institutions), and 19 industry employees (representing all five target disciplines).

3. Survey Results and Discussion

This section opens with a profile of the respondent groups, based on discipline (academia and industry) and Carnegie classification[1] (academia). It then compares the faculty, student, and industry responses regarding content importance. The next material highlights the faculty/student comparison for method of delivery and contributing learning experiences. The closing information addresses the industry/student responses regarding expected and perceived proficiency.

As noted in Table 1, the selected survey topics map to four primary categories. The nature of analyzing the results, however, required a return to a broader brush to assess the impact and provide clearer presentation. As such, the results in this section are presented in two groups: (1) technical skills (includes problem definition and design categories) and (2) professional skills (includes shared collaboration and leadership categories).

3A) Respondent Profile

Respondents represented a range of engineering disciplines, as shown in Figure 1. Note that the pilot group invited to participate in the survey included representatives from Civil Engineering (CE), Chemical Engineering (ChE), Electrical Engineering (EE), General Engineering (GE), and Mechanical Engineering (ME). The "Other" responses largely represented computer science, especially for industry. Some faculty and students did not list their discipline, hence the small "Don't Know" category. Overall, all five of the target disciplines were represented in each of the respondent populations, with low ChE numbers from both students and industry, and low GE numbers in industry.

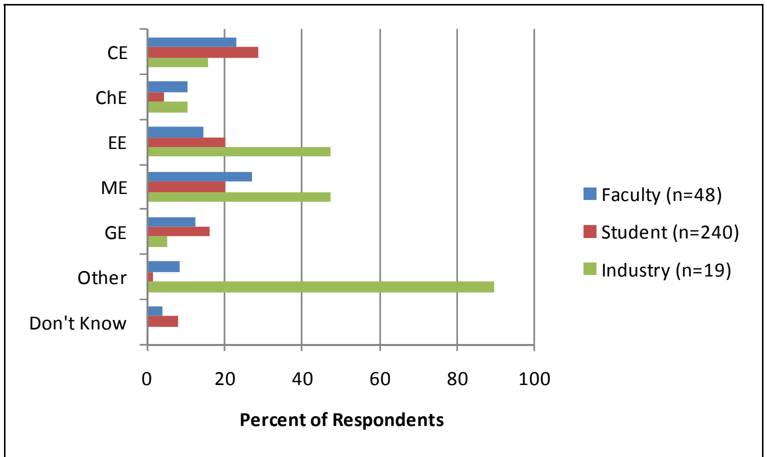


Figure 1 – Profile of Respondents by Discipline

The academic responses represented a total of 24 institutions, distributed widely across Carnegie classification. Figures 2-4 depict the institutional representation based on Carnegie classification of institution type, size, degree and research level, respectively. As shown in Figure 5, the institutions also represent geographic diversity.

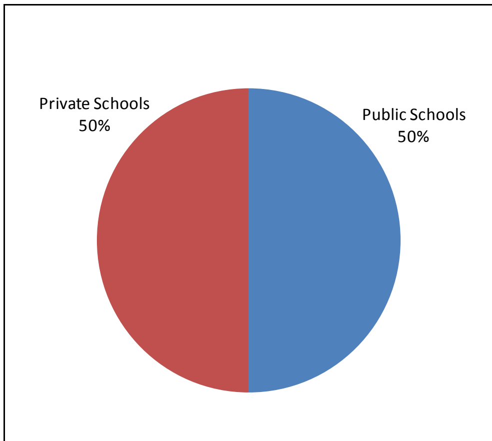


Figure 2 – Respondent Institution Type (n=24)

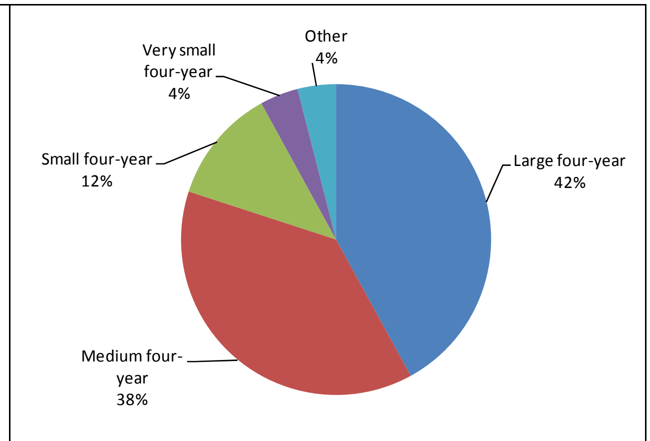


Figure 3 – Respondent Institution Size (n=24)

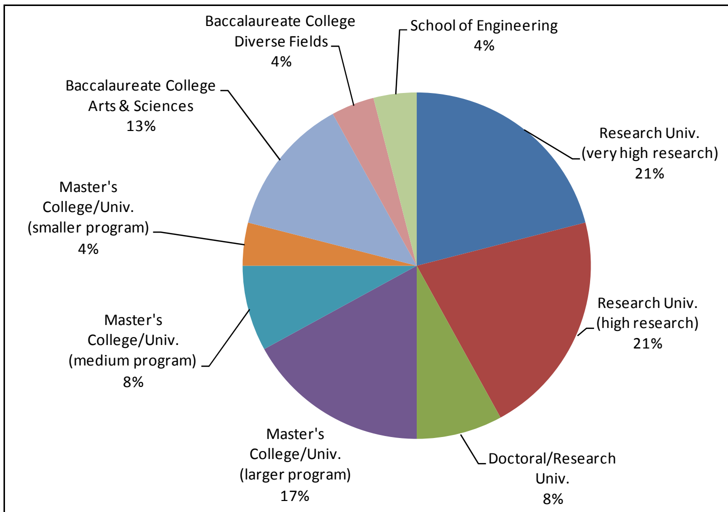


Figure 4 – Respondent Institution Degree and Research Level (n=24)

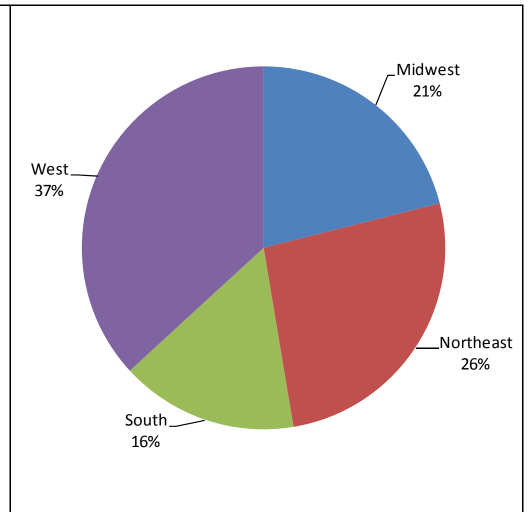


Figure 5 – Respondent Institution Location (n=24)

Faculty members who received the survey link were asked, in addition to completing the survey themselves, to send a link with the survey to their students encouraging them to take the student survey too. Hence, respondent pairings of faculty and students were expected. Figure 6 shows the numbers of students associated with a given faculty member or a group of faculty from the same department, for those faculty and students who clearly reported their discipline; each circle on the chart represents one set of students with its respective faculty member(s). As is clear from the figure, the majority of faculty responses are connected with 0-4 student responses, though a few faculty members had 19 or more students from their class(es) respond.

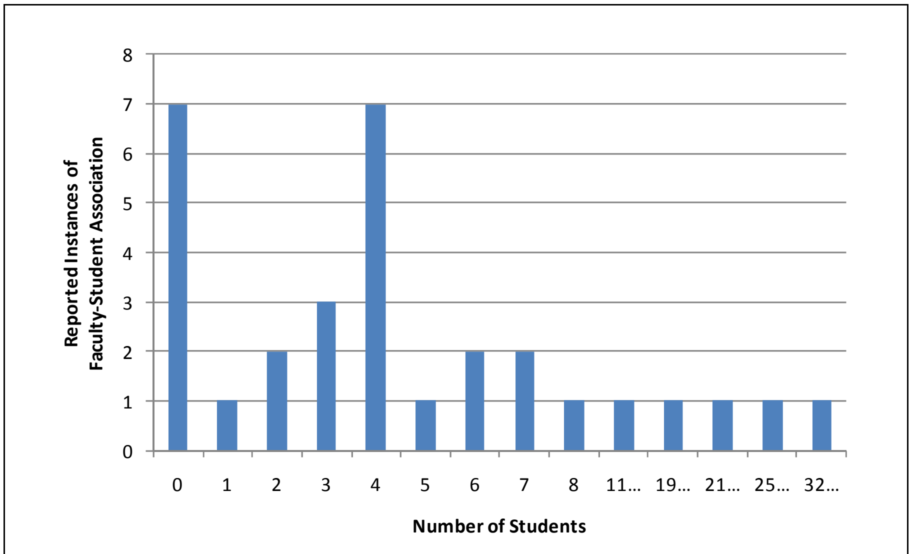


Figure 6 – Numbers of Students Associated with a Faculty Member

One of the open-ended questions on the faculty survey asked respondents whether they had worked in industry and, if so, for how many years. Figure 7 shows the faculty response; responses were rounded to the nearest year. As is clear from the figure, the range of faculty experience in industry varied widely; about half of the faculty respondents had less than five years experience in industry, nearly 20% had not worked in industry at all. On the other extreme, 11% had worked more than 25 years.

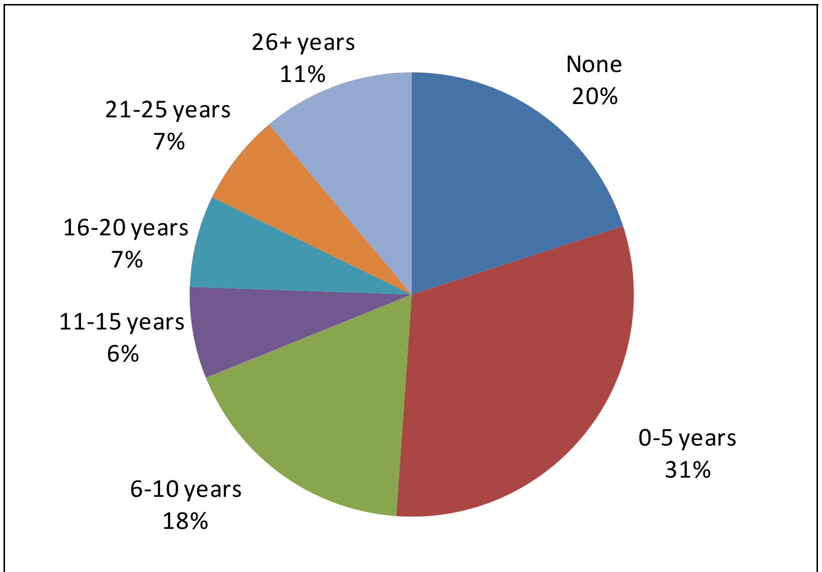


Figure 7 – Years of Faculty Experience in Industry (n=48)

3B) <u>Content Importance</u>

All three surveys asked respondents to rate each topic on a scale of importance (high, medium, low) and, of those topics rated "high", to select the most important, second most important, and third most important topic. Faculty were asked to rate the importance of the topics for student learning/development (in general), whereas students were asked to rate the importance of the topics for their own learning/development. Industry respondents were asked to rate the topic importance for new employee learning/development.

The faculty responses for topic importance are shown in Figure 8a-8b, divided by technical and professional topics. Respondents were required to select one rating (high, medium, low, N/A) for each topic and were not limited to the number of "high" ratings. The graphs do not show the "N/A" responses so the number of responses varies for each topic. Note that majority of faculty respondents rated the majority of technical topics as "high", whereas the ratings for the professional topics were mixed, with many receiving more "medium" ratings than "high" ratings. Few faculty respondents rated any of the topics as "low" in importance for student learning/development.

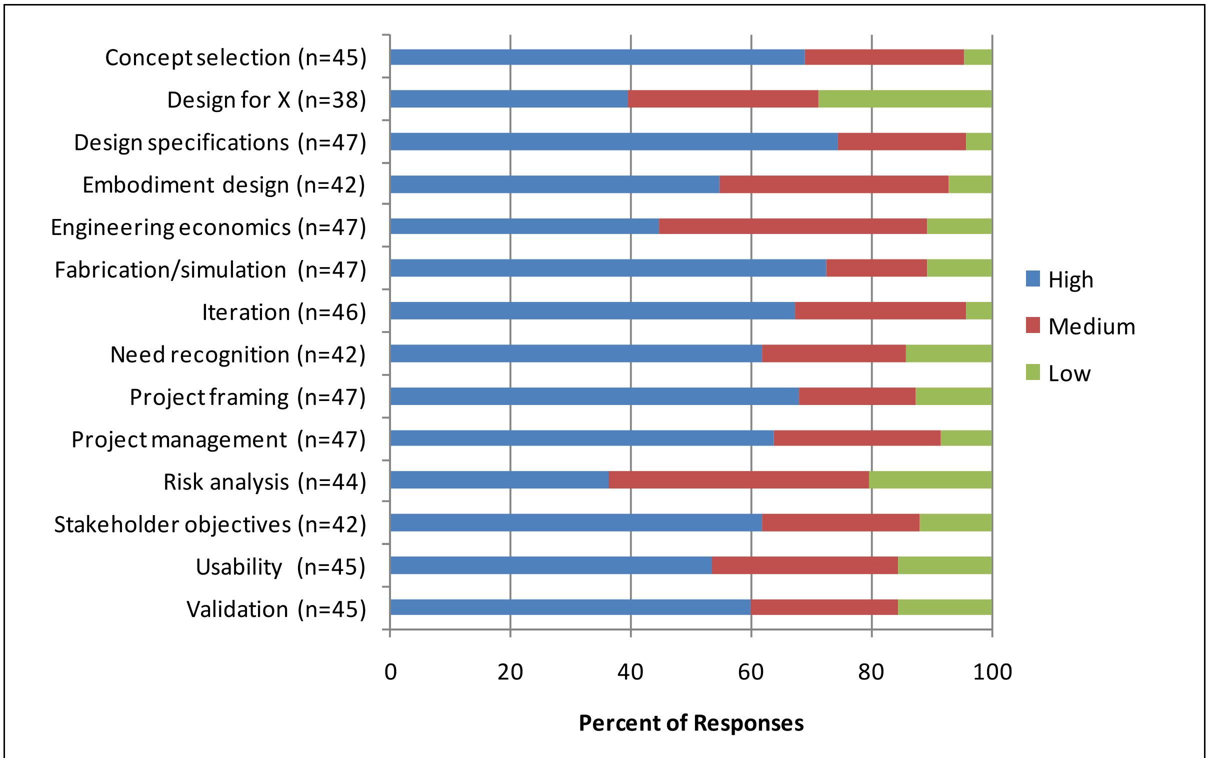


Figure 8a – Faculty Responses for Topic Importance (Technical Topics)

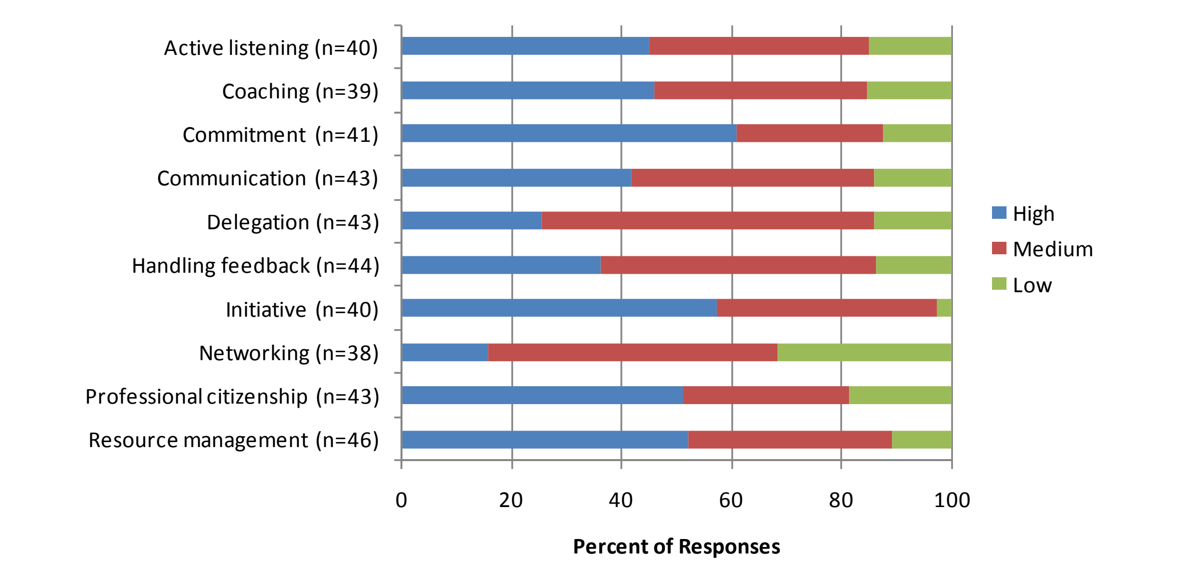


Figure 8b – Faculty Responses for Topic Importance (Professional Topics)

Figures 9a-9b show the most important topics for faculty respondents, again divided by technical and professional topics. In keeping with their responses about overall importance, the faculty respondents overwhelmingly selected technical topics (from the entire set of topics) as their most important. Fabrication/simulation was the most popular favorite topic among faculty respondents; nearly 20% of faculty selected it as their most important topic, and 35% of faculty listed it in their top three.

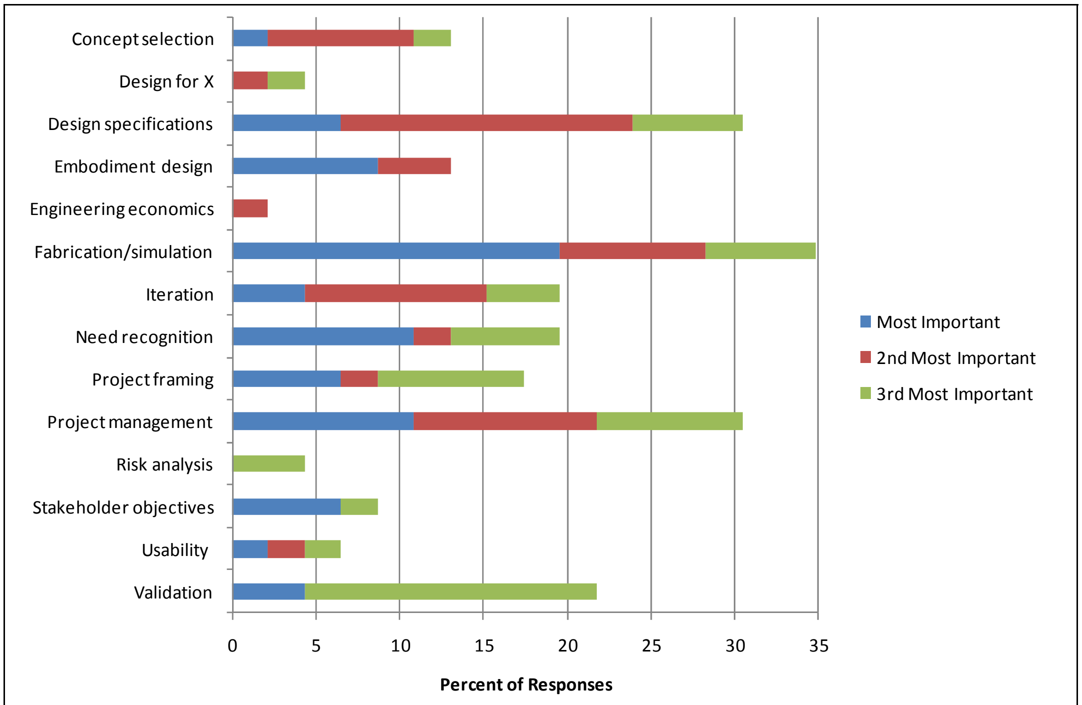


Figure 9a – Faculty Responses for Most Important Topics
(Technical Topics, n=46)

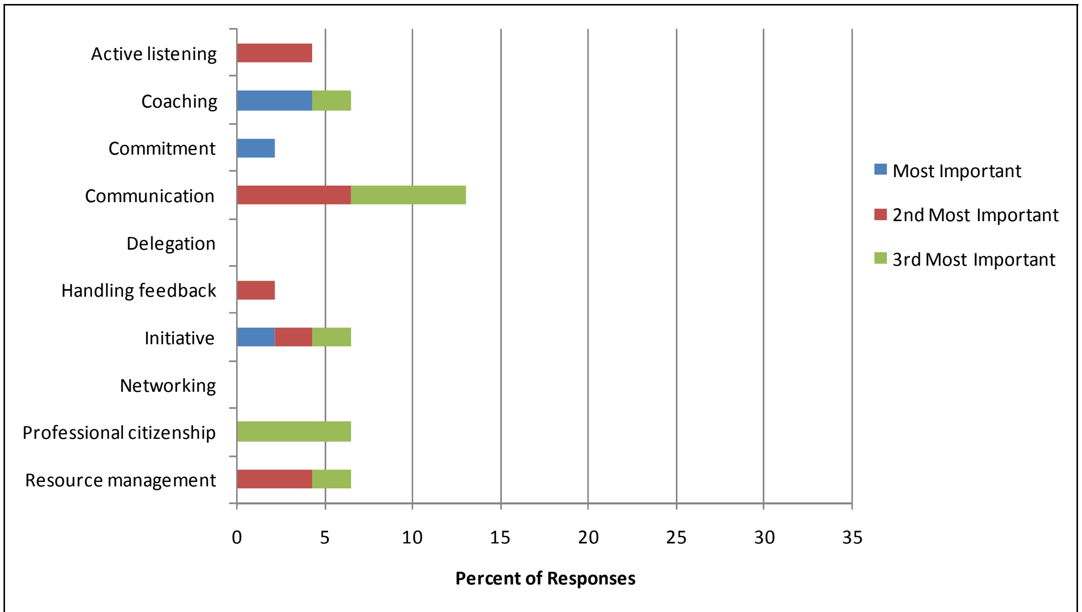


Figure 9b – Faculty Responses for Most Important Topics (Professional Topics, n=46)

Faculty were also asked in the open-ended response section what aspects of their course best serve student learning. Themes emerging from a content analysis included communication, design process, faculty interaction, multi-disciplinarity, personal growth, planning, project outcome, real world, and teamwork. Ninety percent of respondents (n=46) commented about the real-world nature of the project or the experience and just over 50% mentioned exposure to the design process. It is interesting to note the number of professional topics that emerged from these qualitative responses, especially given the importance faculty placed on technical topics in a previous question.

Student responses for topic importance are shown in Figures 10a-10b. Unlike the faculty response, students rated both technical topics and professional topics fairly evenly, with many topics receiving more "high" ratings than "medium" or "low". Differences across discipline were not substantial between CE, EE, and ME respondents, but the students from ChE tended to rate topics lower than did their counterparts from other disciplines, whereas students from GE programs on average rated topics higher than did their counterparts.

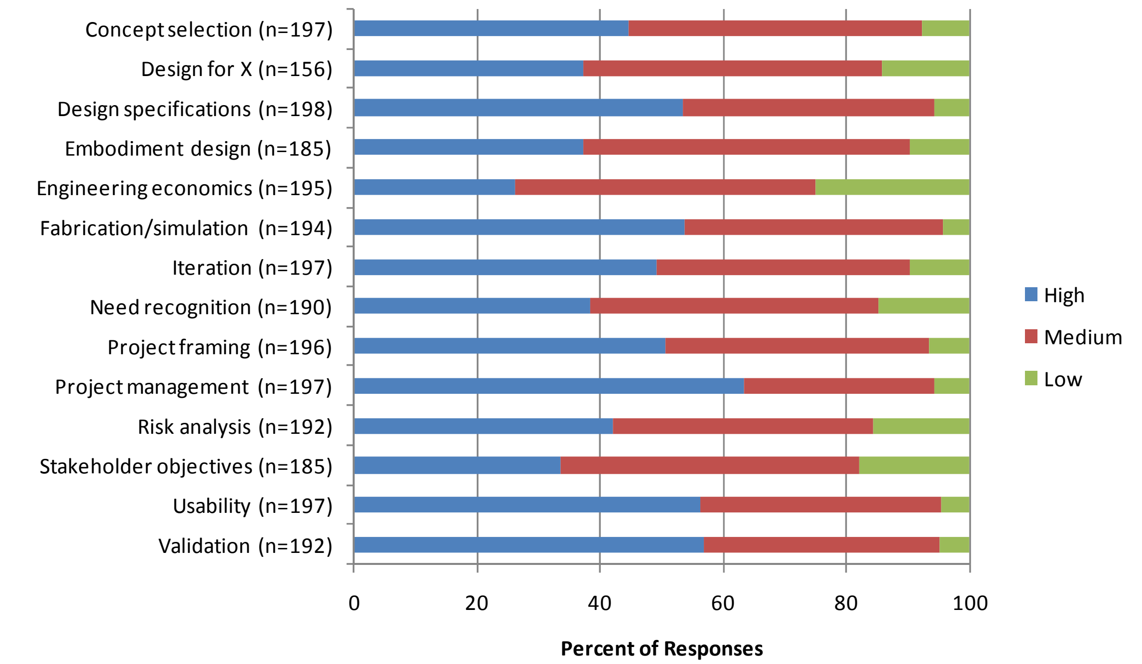


Figure 10a – Student Responses for Topic Importance (Technical Topics)

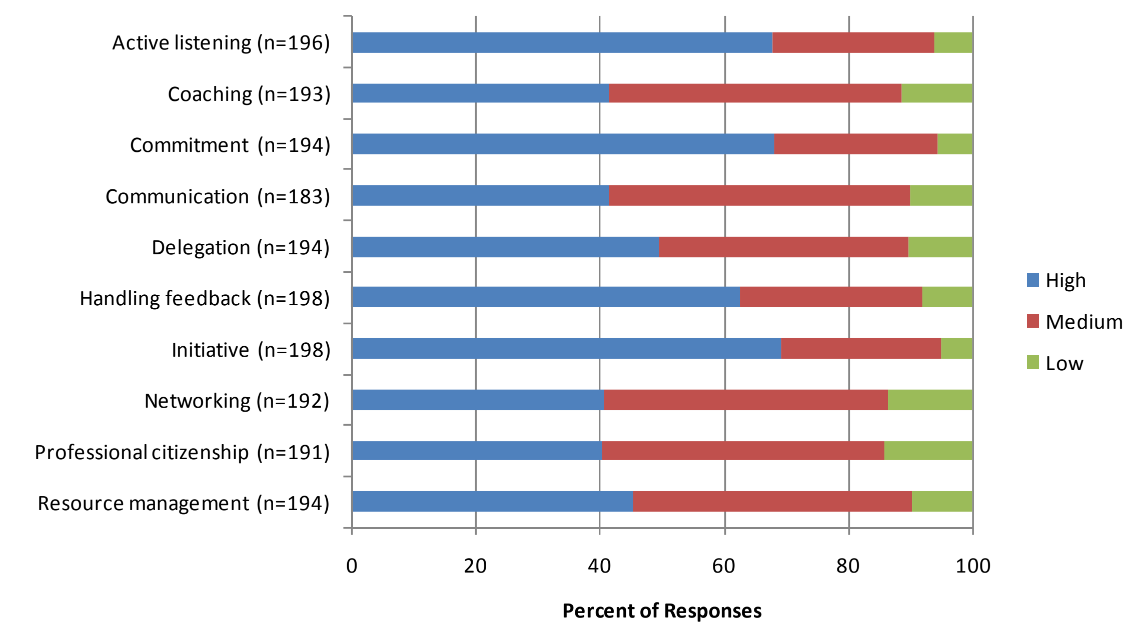


Figure 10b – Student Responses for Topic Importance (Professional Topics)

Figures 11a-11b show student response with regard to most important topics. Here again, students were fairly balanced between technical and professional topics, but slightly favored professional topics. Active listening received the largest number of votes overall, followed closely by both initiative and commitment. The technical topics of project management and fabrication/simulation were also rated highly by students.

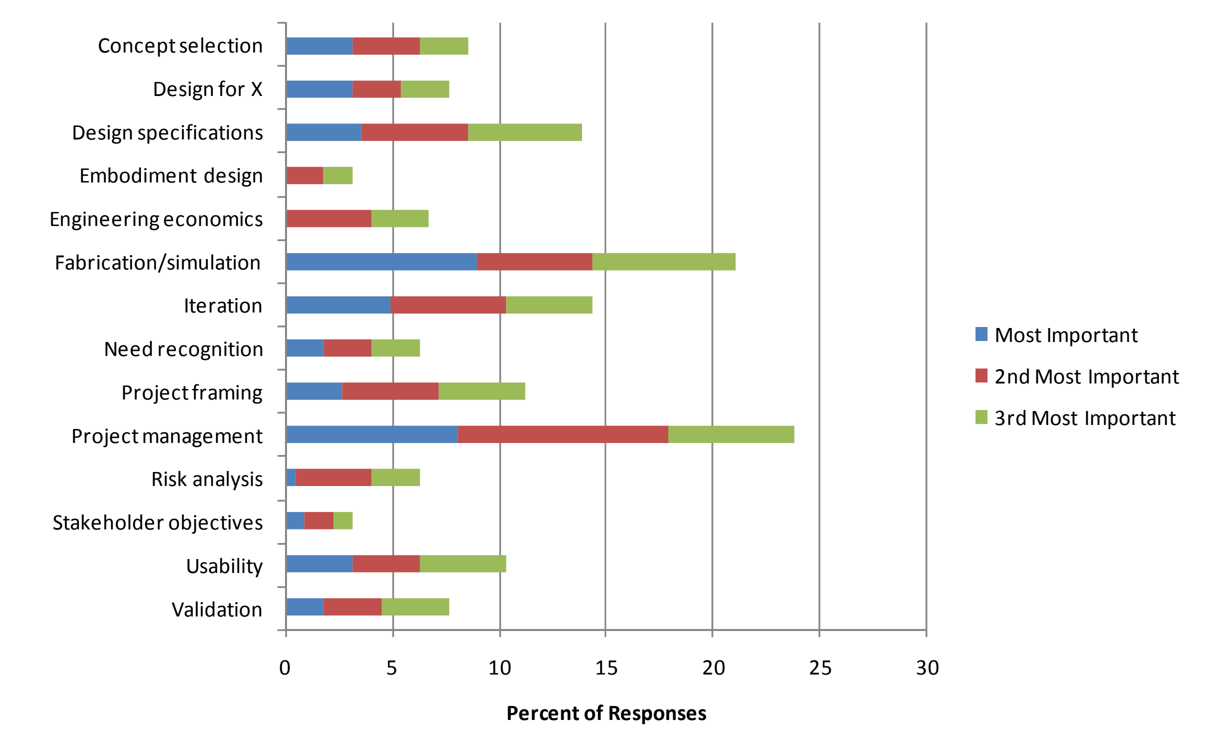


Figure 11a – Student Responses for Most Important Topic
(Technical Topics, n=223)

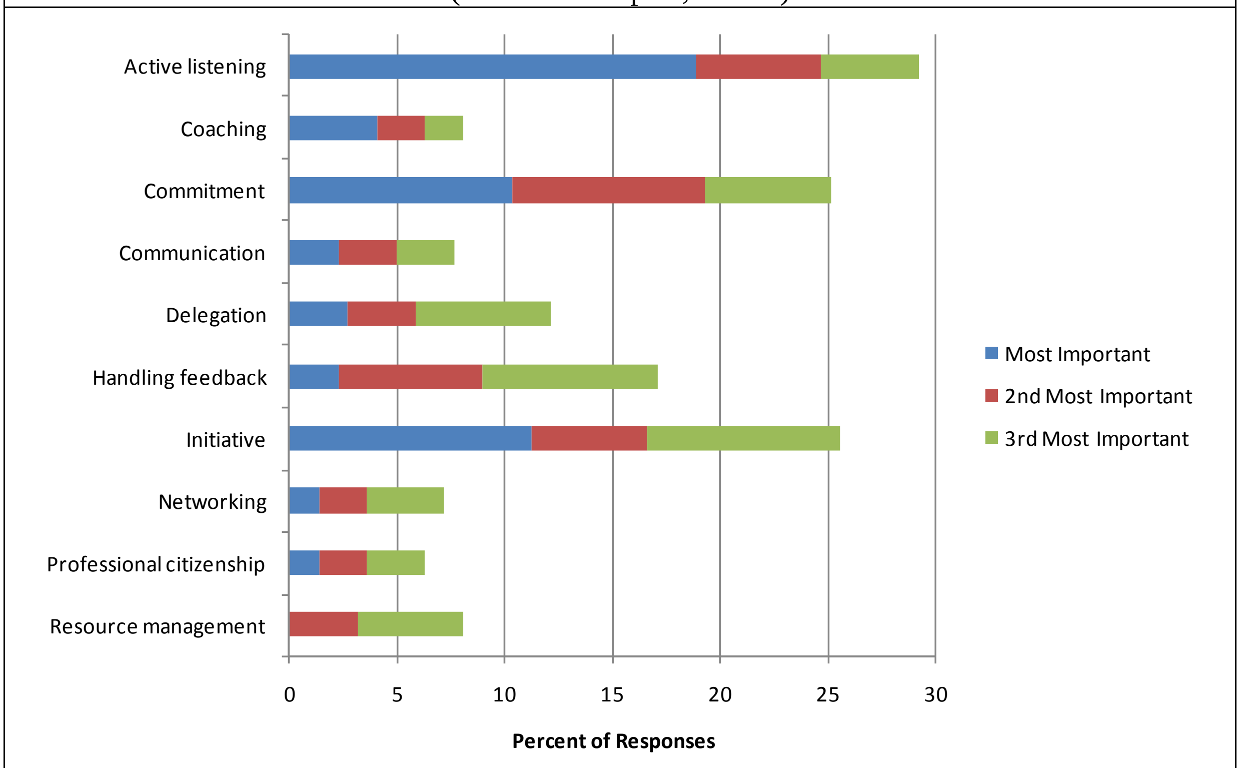


Figure 11b – Student Responses for Most Important Topic
(Professional Topics, n=223)

Those topics students in different disciplines selected as most important are depicted in Table 2. The middle column lists the topic with the most "most important" votes, whereas the right-hand column shows the topic with the most cumulative votes: most important + 2nd most important + 3rd most important. Note that in nearly all cases, the most often selected topic is a professional topic, with active listening as the favorite.

Table 2: Most Important Topics for Student Respondents by Discipline

Discipline	**Highest Rated Topic**	
	Most "Most Important" Votes	Most Cumulative Votes
CE (n=66)	Active Listening	Active Listening
ChE (n=9)	Commitment/Project Management (*tied*)	Commitment/Initiative (*tied*)
EE (n=46)	Active Listening	Active Listening
GE (n=38)	Active Listening	Active Listening
ME (n=51)	Initiative	Commitment/Initiative (*tied*)

Industry responses for topic importance are shown in Figures 12a-12b. These results are striking; the industry respondents overwhelmingly rated professional topics higher than technical skills. In fact, five of the ten professional topics received a rating of "high" from between 60-90% of the industry respondents, whereas the highest rated technical skill received "high" ratings from less than 30% of respondents. Moreover, the number of "low" ratings assigned by industry was much lower for professional topics than for technical topics.

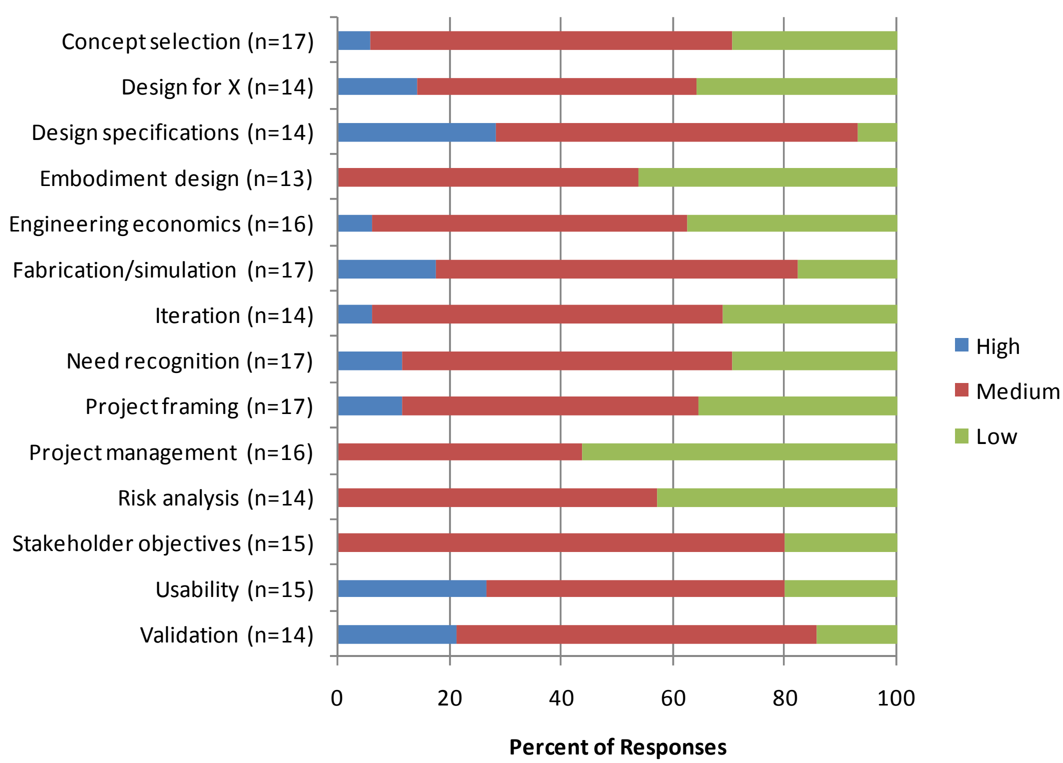


Figure 12a – Industry Responses for Topic Importance (Technical Topics)

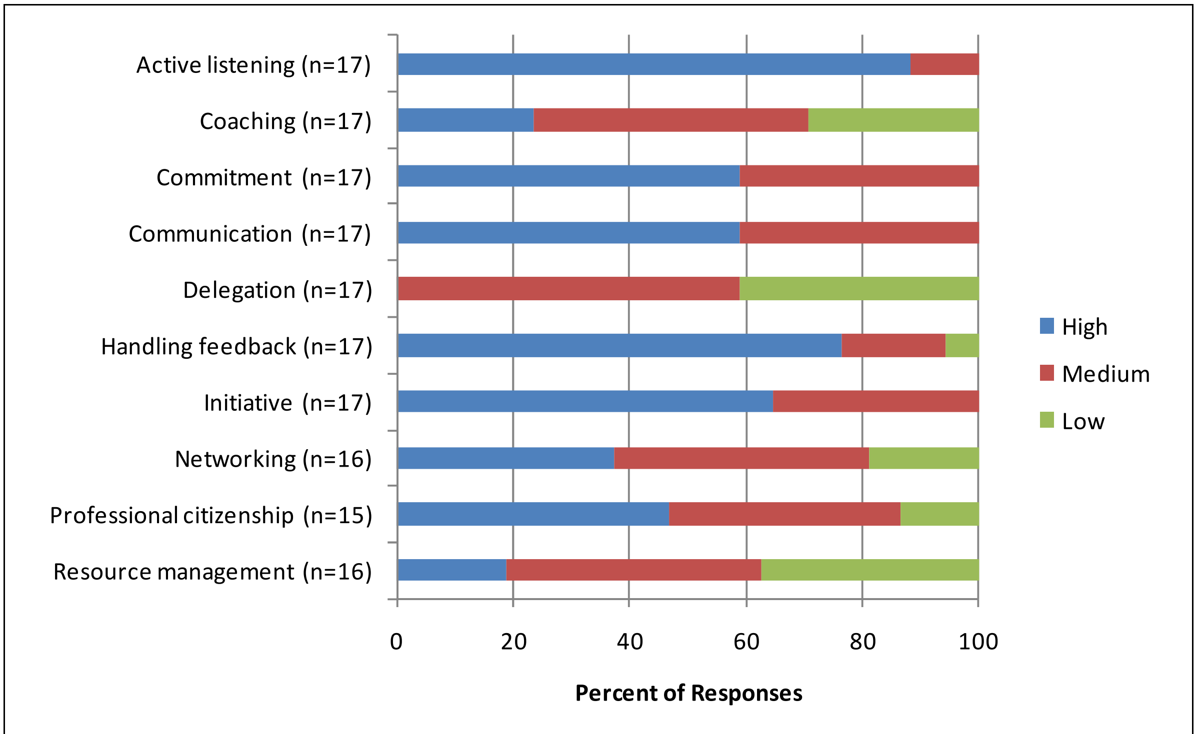
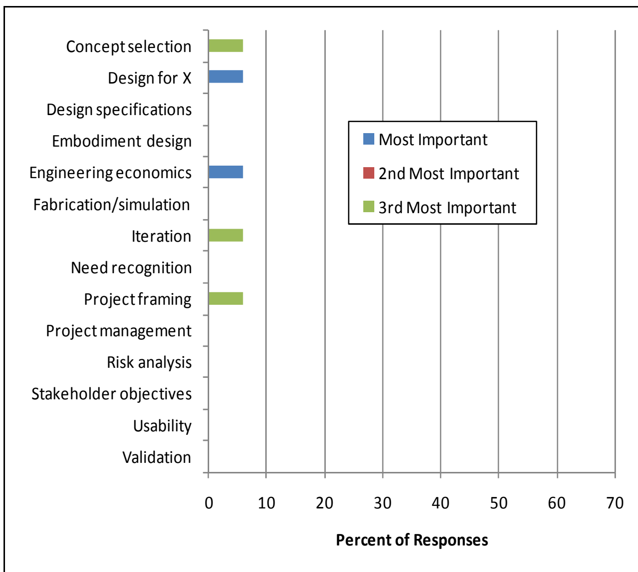
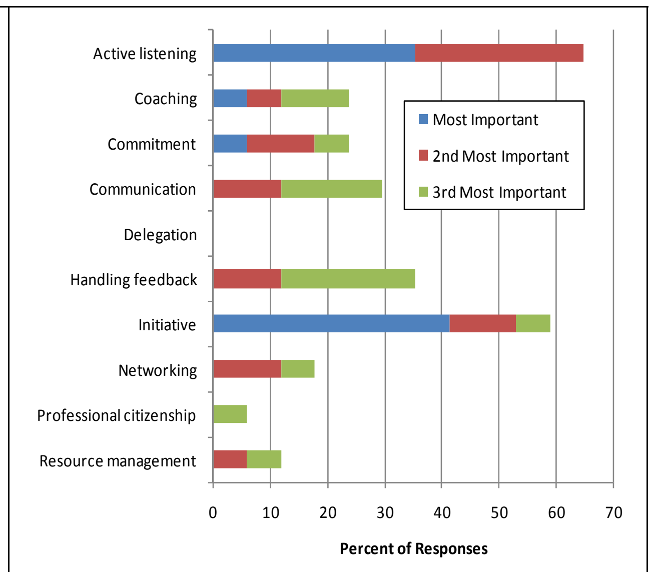


Figure 12b – Industry Responses for Topic Importance (Professional Topics)

Figures 13a-13b show the industry response for most important topic. Note that predominance of votes for professional topics and the dearth of votes for technical topics. Of the topics noted as being of "high" importance, active listening and initiative were selected most frequently by industry respondents as being "most important".



a - Technical Topics



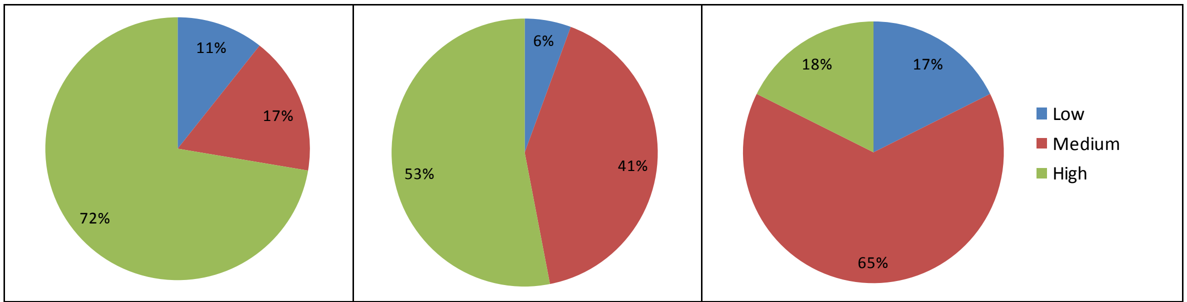
b - Professional Topics

Figures 13a-13b – Industry Responses for Most Important Topics (n=17)

In an open-ended question, industry respondents were asked to explain why they selected the "most important" topics that they did. Several respondents noted that the selected topics were core values of the company. Others stressed the need for employees to take initiative to build their skills and be effective for the company. Others reflected the importance of having employees who can interact with customers. Several suggested that technical competence is expected, but professional competence is necessary for advancement: "It is understood that individuals will have impressive backgrounds when they get here. We find that individuals who have the right attitudes are the ones that succeed." Given this sentiment, it is quite likely that the industry emphasis on professional skills pre-supposes a sufficient baseline level of technical ability.

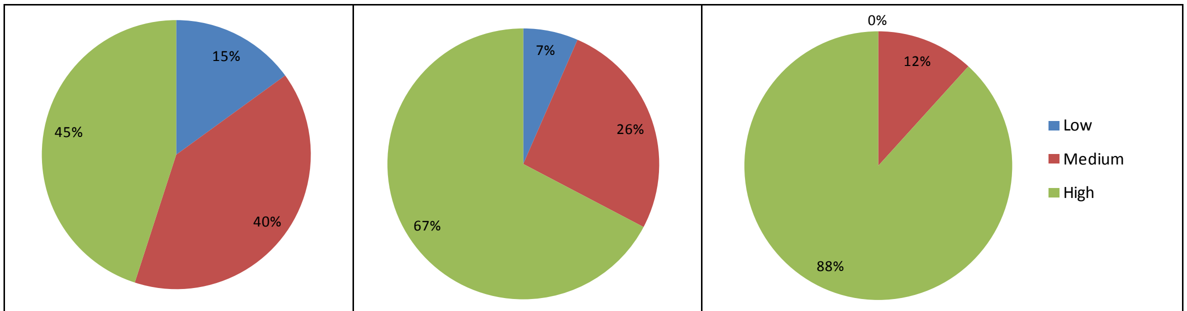
The professional topics deemed most important by industry that did not surface from the academic or student perspective fit the nature of a competitive working environment. Industry responses were blunt in their assessment, e.g., aggressive expectations and schedule to achieve deliverables. A theme of time management appeared to be essential, related to understanding how to behave and act in the environment. More to the point, technical competence was assumed, but getting in tune with the situation – attitude, involvement, and participation – leads to developing management and leadership skills, and in turn advancement and promotion. The first corollary to this outlook is that effectiveness is not necessarily related to technical proficiency. The abilities to take the initiative, to have the willingness to learn, and to accept and act on criticism (mentoring and advice), are an indicator that a young engineer can be productive in any part of the company. The second corollary implies that an entry-level engineer with a strong set of technical and professional foundation skills is in the position to build upon those quickly, acquire new skills and be recognized in the working world.

One way to compare faculty, student, and industry responses directly regarding importance of topics is to focus on specific topics across all three respondent groups. Two such topics – both of which were rated highly by at least one respondent group – are fabrication/simulation (technical) and active listening (professional). Figures 14a-14c show the importance ratings for fabrication/simulation by faculty, student, and industry respondents, respectively. Similarly, Figures 15a-15c show the importance ratings for active listening. In both sets of figures, the difference across respondent groups is evident. For fabrication/simulation, the faculty overwhelmingly rated the topic as "high", students were more evenly divided between "high" and "medium", and the majority of industry respondents rated it only "medium". The results for active listening reveal the opposite trend; just under half of faculty respondents rate active listening as "high", whereas about two-thirds of students and nearly 90% of industry respondents rate it "high". Indeed, these figures illustrate the conclusion from the importance data discussed in this section: faculty lean toward technical topics as most important, industry representatives favor professional topics, and students bridge the gap between their professors and future employers.



Faculty (n=47)	Student (n=194)	Industry (n=17)

Figures 14a-14c – Importance Ratings for "Fabrication/Simulation"



Faculty (n=47)	Student (n=196)	Industry (n=17)

Figures 15a-15c – Importance Ratings for "Active Listening"

3C) <u>Content Coverage: Method of Delivery and Contributing Learning Experiences</u>

Faculty were asked to indicate how they covered different topics in their capstone courses; they could select as many answers as applied from a list of delivery methods. In a related question, students were asked to identify which learning experience (capstone course, previous course(s), internship or employment, and other) contributed to their proficiency with each topic.

Figure 16 shows the average faculty response for method of delivery across both technical and professional topics. The responses for each group of topics sum to more than 100% because faculty could select more than one response. For technical topics, assignments/projects were the most common methods of content delivery, followed by full and partial class sessions. For professional topics, no method of delivery was selected by more than 25% of respondents, and the "not covered" option was as prominent as several other methods. Note, respondents were instructed to select the "N/A" response if they did not want to answer the question or they did not know the response; as such the 6% "N/A" response may reflect faculty members who do not know how they cover a particular topic.

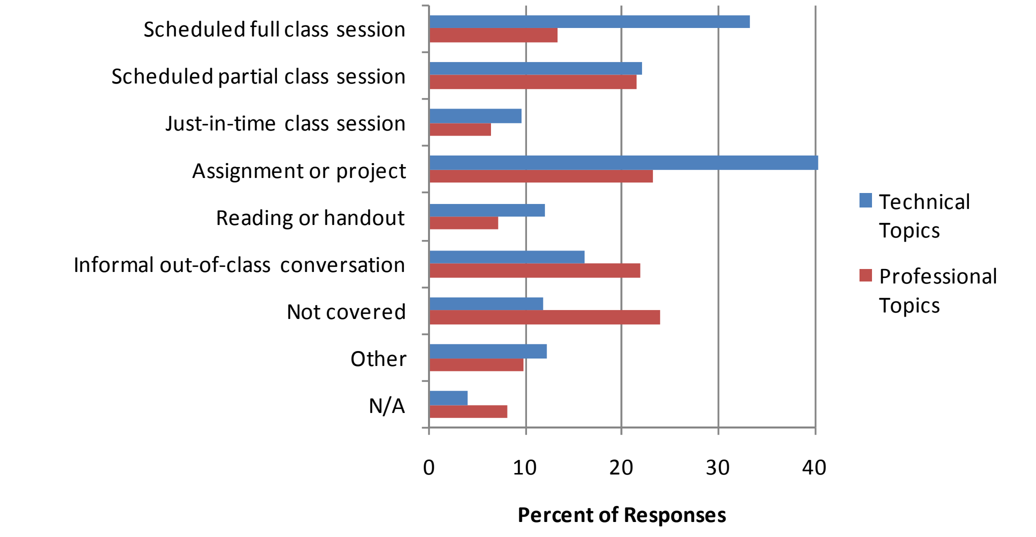


Figure 16 – Method of Delivery (n=48)

Figures 17a-17b show the reported methods of delivery for each topic, separated by technical and professional skills. Given that faculty rated technical skills as especially important, it is not surprising that more than half of faculty cover all the technical skills in a full and/or partial class session, and nearly half address the technical skills with an assignment or project. While faculty reported covering professional skills in a variety of ways as well, the focus was less on full scheduled class sessions and more on a mix of partial class sessions, assignment/project, informal discussion, and not covering the topic at all.

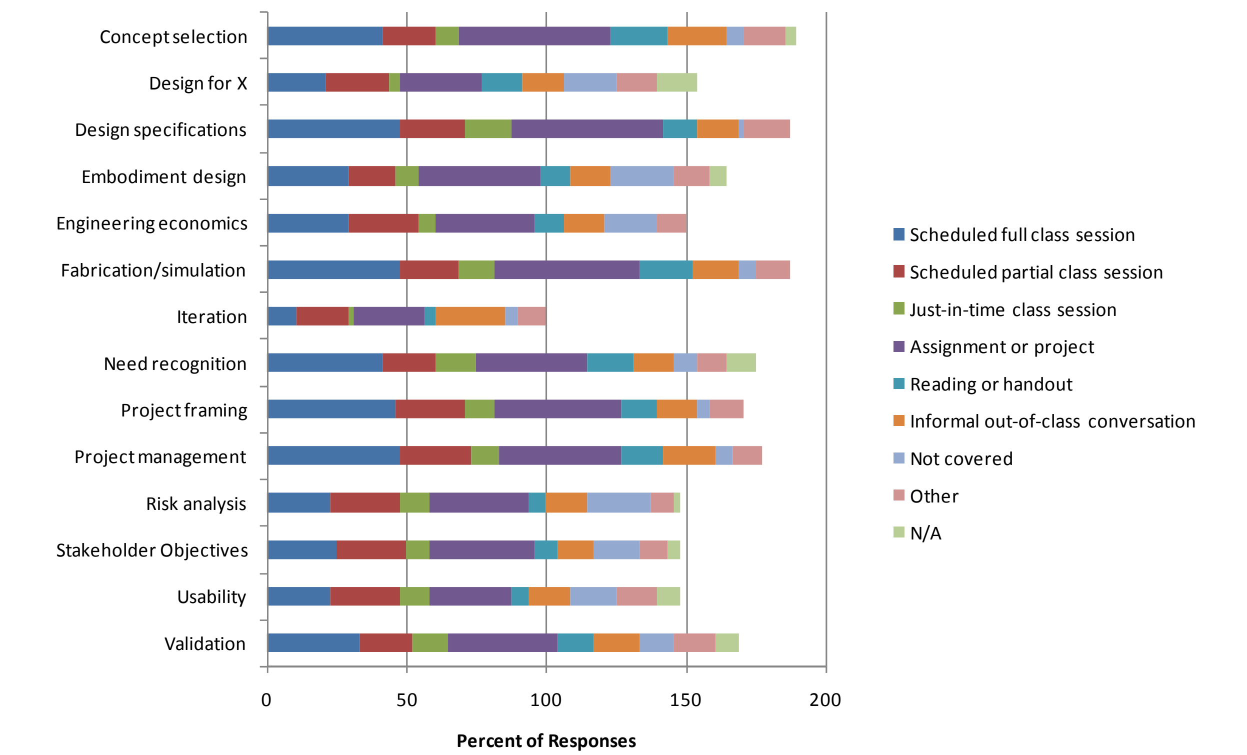


Figure 17a – Method of Delivery by Topic (Technical Topics, n=48)

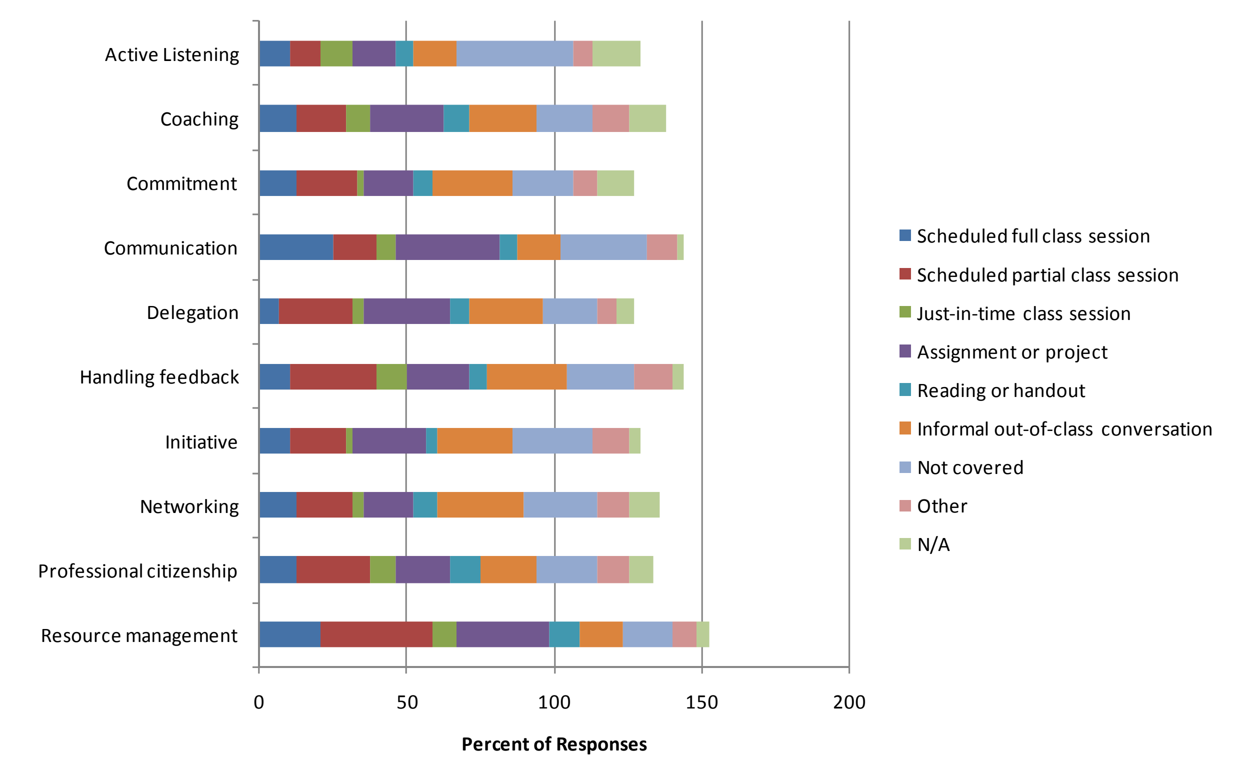


Figure 17b – Method of Delivery by Topic (Professional Topics, n=48)

Figure 18 shows the average student response, across both technical and professional, of which learning experiences contributed to their proficiency with the topics. While students gained knowledge about both technical and professional topics from their capstone course, they also, as expected, learned from previous courses, internships, and other experiences, especially for professional topics.

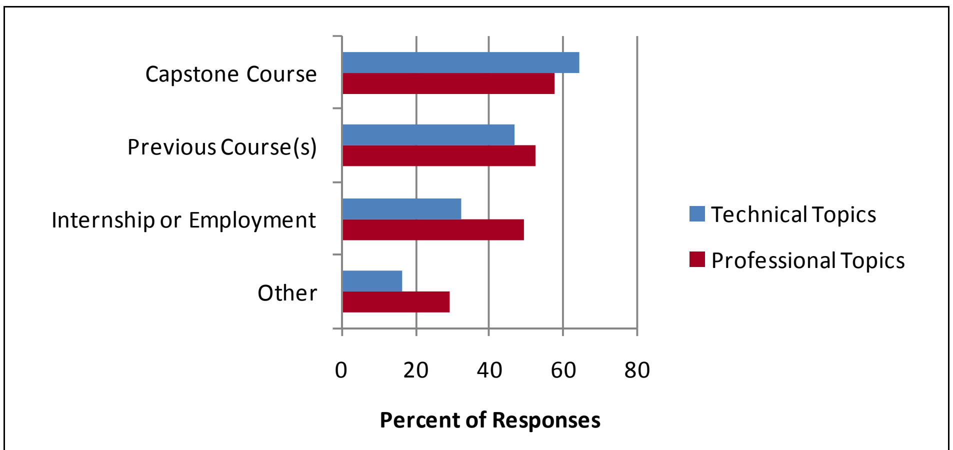
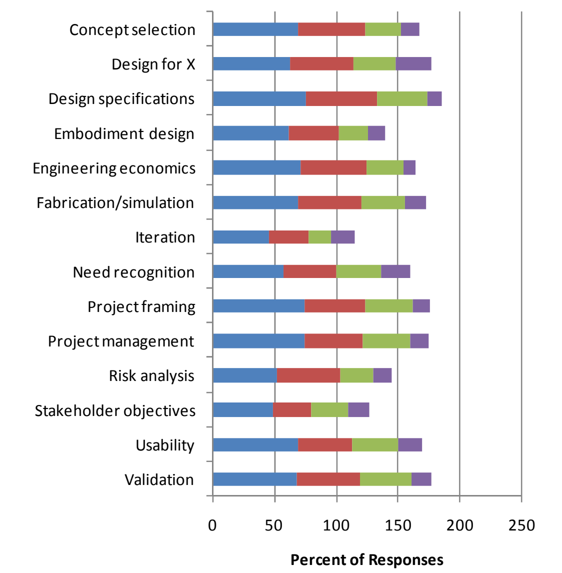
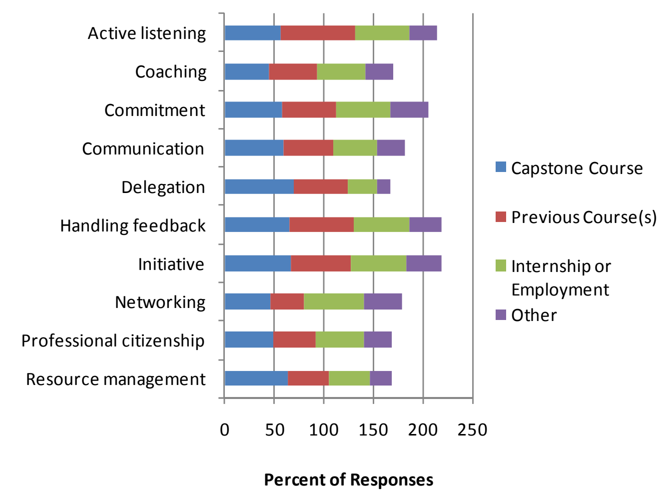


Figure 18 – Where Students Gained Proficiency, across All Topics (n=235)

Figures 19a-19b provide further detail about which experiences contributed to student knowledge gain, this time for individual topics, divided by category. In both charts, the responses sum to more than 100%, implying that most students selected more than one answer for each topic. For technical skills, students most frequently noted gaining knowledge in their capstone course, followed by previous courses. Student response was more even for professional skills, with capstone courses, previous courses, and internship experiences selected about evenly. It is worth noting that students recognized their learning of professional skills in capstone courses, even though faculty covered them more informally and placed greater importance on technical skills.



a – Technical Topics



b – Professional Topics

Figures 19a-19b – Where Students Gained Proficiency in Specific Topics (n=235)

As a specific comparison of faculty and student response regarding topic coverage and topic learning, Figures 20a-20b and 21a-21b isolate the results for an important technical skill – fabrication/simulation – and an important professional skill – active listening. The majority of faculty respondents gave an assignment or project that addressed fabrication/simulation and a sizable minority dedicated a full class or partial class session to it. More than two-thirds of students, in turn, noted increasing proficiency with fabrication/simulation in their capstone course. In contrast, about 40% of faculty respondents noted they do not cover active listening, and only few respondents noted other methods of delivery for the topic. Yet, more than half of students noted that the capstone experience contributed to their increased proficiency with the topic. Not surprisingly, students perceived that they learned more from the capstone course than simply the material that the faculty covered or assigned; how much more and how well is a subject for a future study.

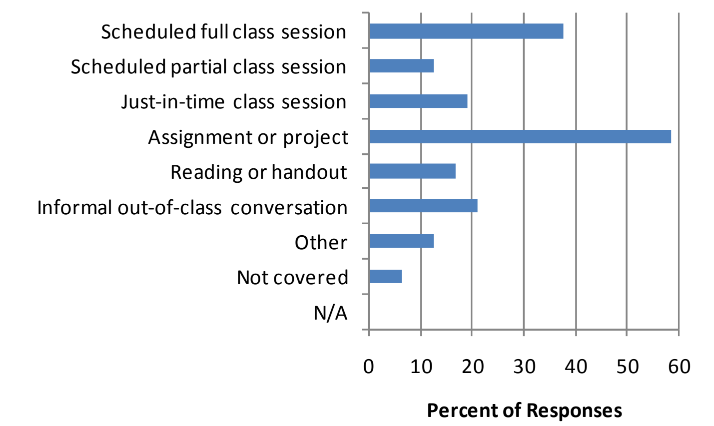


Figure 20a – How Faculty Covered "Fabrication/Simulation" (n=48)

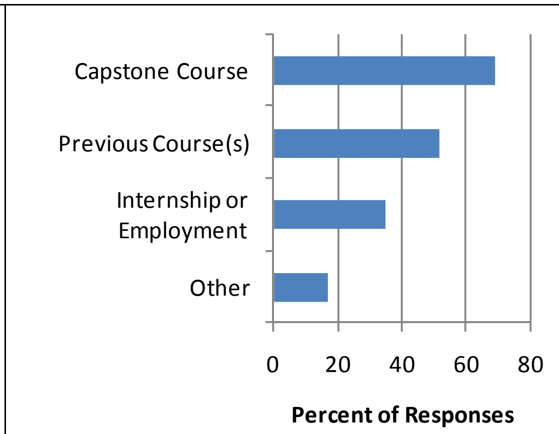


Figure 20b – Where Students Gained Proficiency in "Fabrication/Simulation" (n=235)

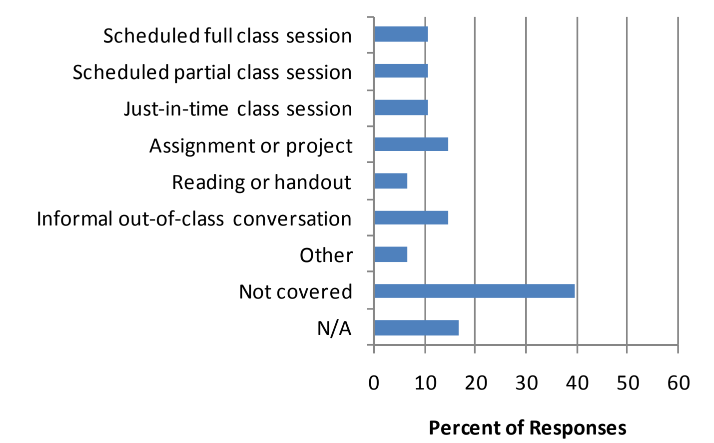


Figure 21a – How Faculty Covered "Active Listening" (n=48)

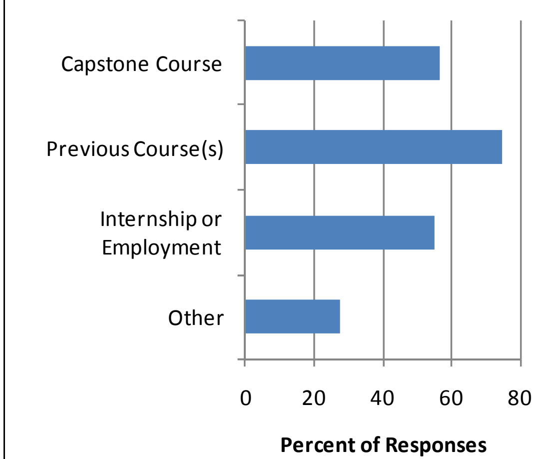


Figure 21b – Where Students Gained Proficiency in "Active Listening" (n=235)

3D) <u>Content Proficiency: Perceived and Expected</u>

The pilot study surveyed students regarding their perceived proficiency near the end of their capstone experience. When interpreting these results, it is worth noting that no pre-test data were collected, hence students' change in perceived proficiency because of their capstone experience cannot be discussed. Moreover, the pilot survey did not attempt to compare perceived proficiency with actual performance; this is a subject for future work.

The survey of student perception of their own proficiency upon the completion of the capstone course reveals that over fifty percent of respondents believed they are skilled in the practice or implementation of or able to participate in and contribute to the set of topics. More interesting is the finding that 12% of students in the survey believed they were able to lead or innovate in various technical topics and 21% of students believed they were able to lead or innovate in professional topics. Figure 22 clearly shows a slant in favor of proficiency as the student's self-perception, especially for professional topics, though a few respondents noted a lack of familiarity with at least some of the topics.

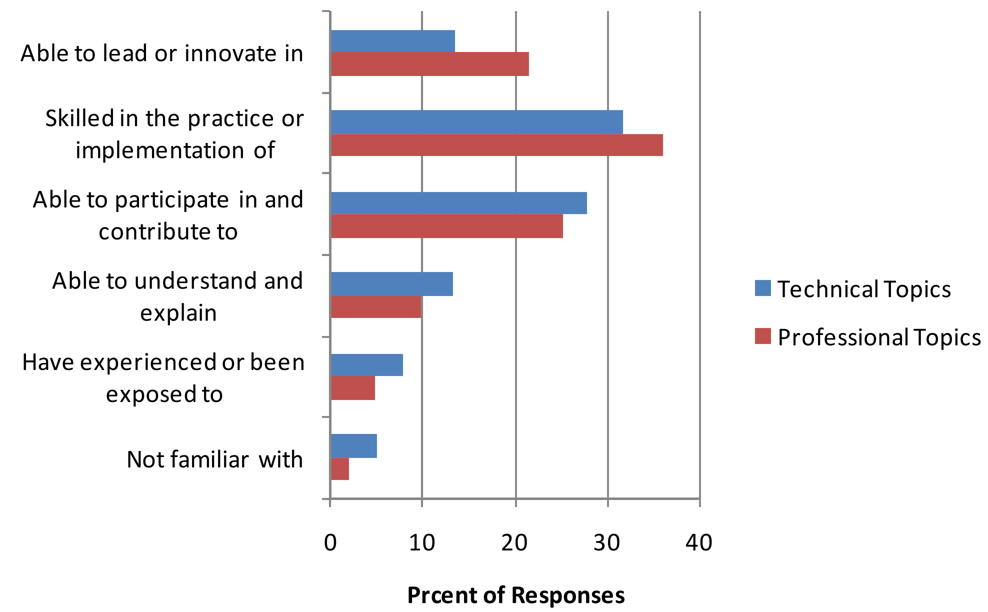


Figure 22 – Average Student Perceived Proficiency across All Topics (n=216)

Figures 23a-23b probe the student perception in more detail by detailing the survey results for each of the topics listed in Table 1.   A comparison between the two figures reveals that students believed that they are more "skilled" in the professional topics than in the technical ones, and have a greater ability to "lead and innovate" in the professional topics as well.   Overall in both figures, the high level of ability perceived by students is evident, for in the technical topics nearly 70% of students thought their proficiency was at the level of "able to participate" or better, while in the professional skills the response in the top three categories was approximately 80%.

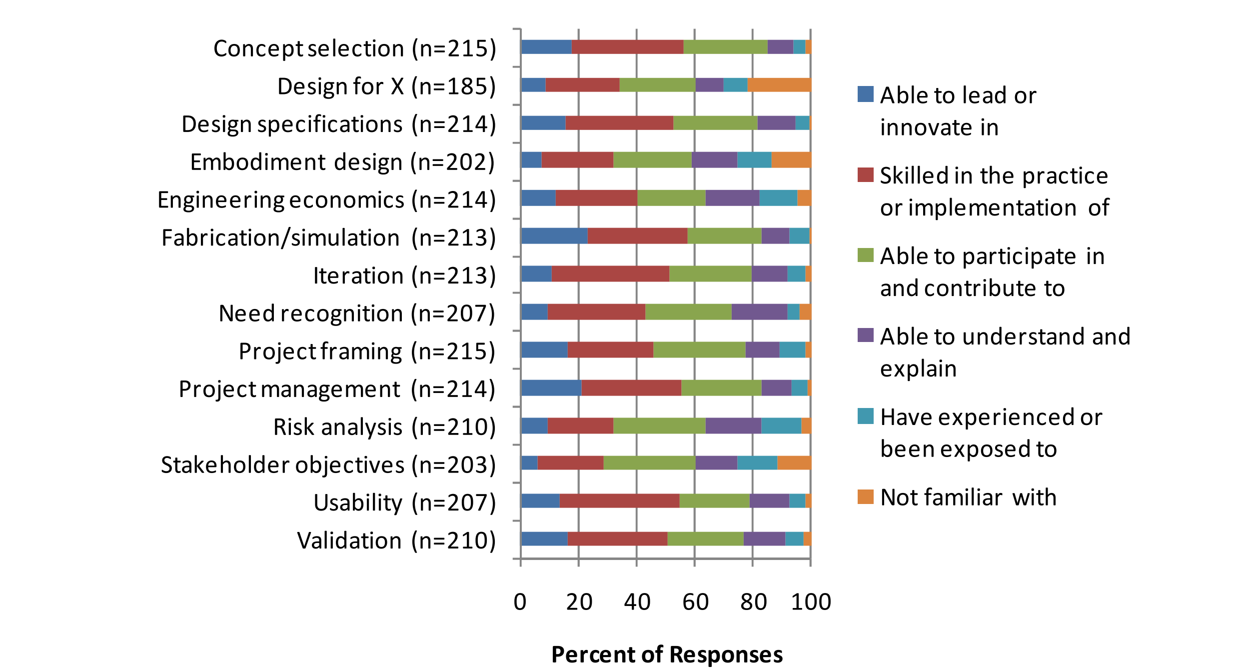


Figure 23a – Student Perceived Proficiency (Technical Topics)

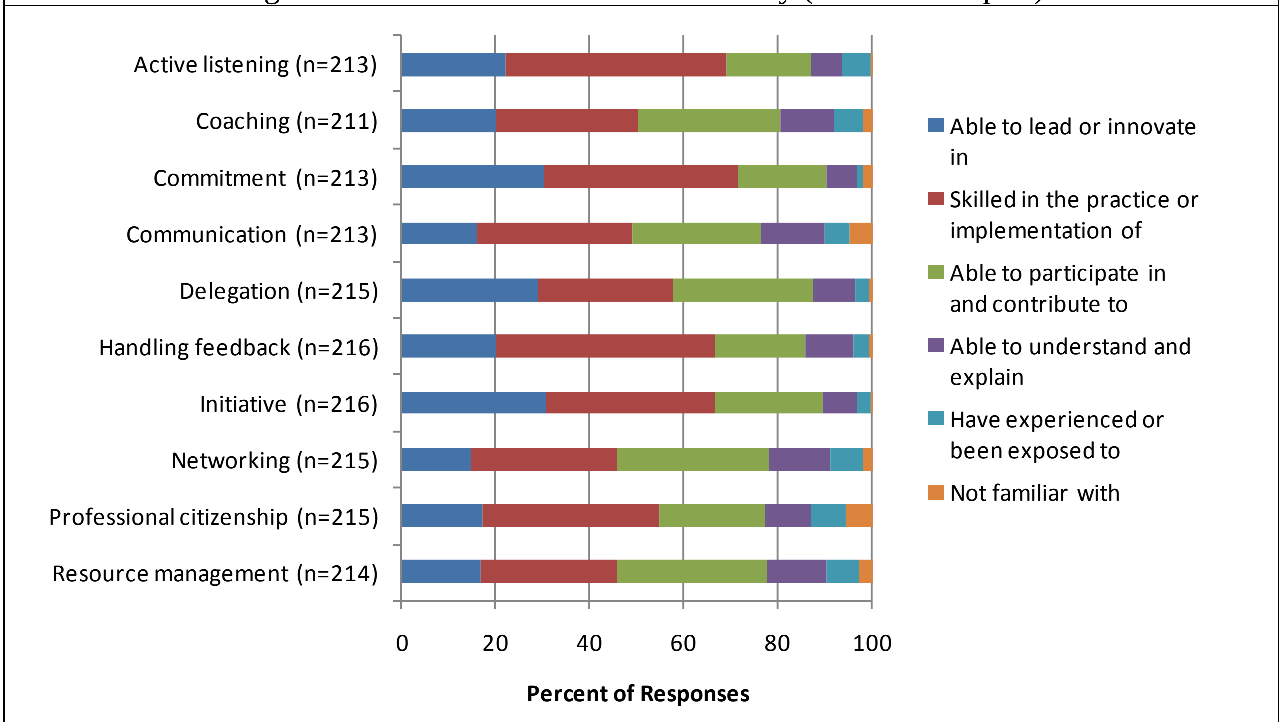


Figure 23b – Student Perceived Proficiency (Professional Topics)

One open-ended question asked industry respondents what knowledge/attributes/skills they thought were most evident in entry-level employees. Results from a content analysis suggest that while entry level employees exhibit a desire and ability to learn, they also demonstrate a mix of both technical (computer/technical skills, problem solving, research ability) and professional skills (adaptation, communication, energy, networking). As one respondent noted, "Most of our entry level engineers are very skilled in engineering concepts and are very motivated to learn."

In a similar vein, industry respondents were also asked what knowledge/attitude/skills they thought were lacking in entry-level employees. Content analysis revealed a preponderance of themes related to professional skills (communication, leadership, management, networking, patience, planning, and willingness to challenge the status quo). Only one respondent noted any specific technical skill: verification. However, 40% of respondents commented that entry-level employees were lacking experience with the real world and knowledge of a professional environment, as typified by the following response: "We see graduates who are experts in subject matter and tools, but what is lacking is the knowledge of how that information and those tools are utilized in a professional work environment."

Figure 24 shows that industry expectations of entry-level engineers overall follow a rough Gaussian distribution, centered on "able to participate in or contribute to". As such, very few industry respondents expect entry-level engineers to be able to lead or innovate in a given topic, but all respondents expect their new hires to have a basic familiarity with all of the topics given in Table 1. Even more interesting is the contrast between industry expectations for professional skills versus technical skills; of the two, industry expects entry level graduates to be more proficient with professional skills. The distribution of industry expectations in Figure 24 does not match from the distribution of student perceived proficiency in Figure 22; indeed students perceive an ability to lead or innovate, yet industry rarely expects them to be able to do so.

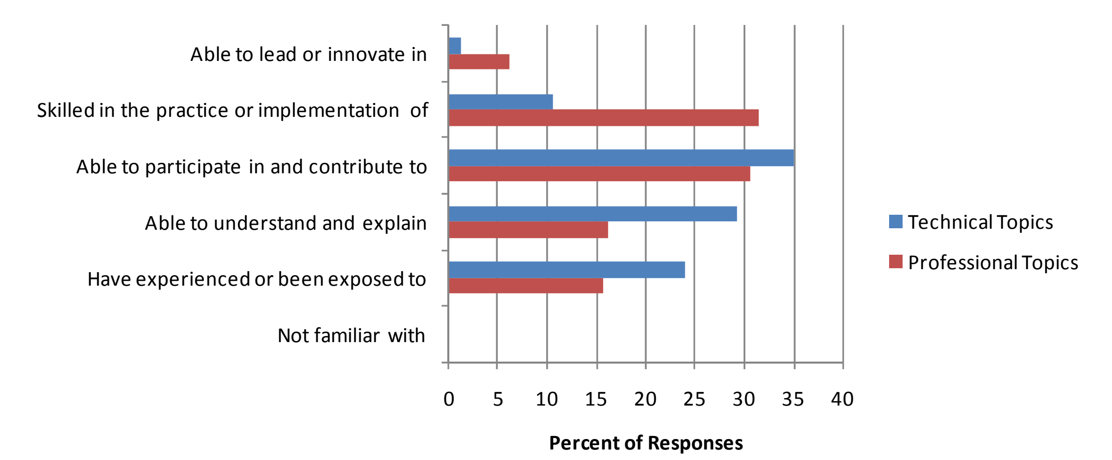


Figure 24 – Industry Respondents: Expected Proficiency of Entry-Level Engineers (n=18)

The detailed industrial expectations regarding both technical and professional topics are exhibited in Figures 25a and 25b, respectively. Note in Figure 25a the paucity of responses at the proficiency level of "able to lead or innovate in". Figure 25b shows more responses at the highest proficiency level and a comparison of the two graphs reveals much higher overall industry expectations for professional topics than for technical ones. Industry expectations at the top two levels of proficiency ("able to lead/innovate in" and "skilled in practice/implementation of") are highest for taking initiative, followed by communication, commitment, handling feedback, and active listening. Industry respondents expect entry-level employees primarily to be able to understand or participate in the majority of technical topics, whereas they expect an ability to participate in or skill in the practice of the majority of professional topics.

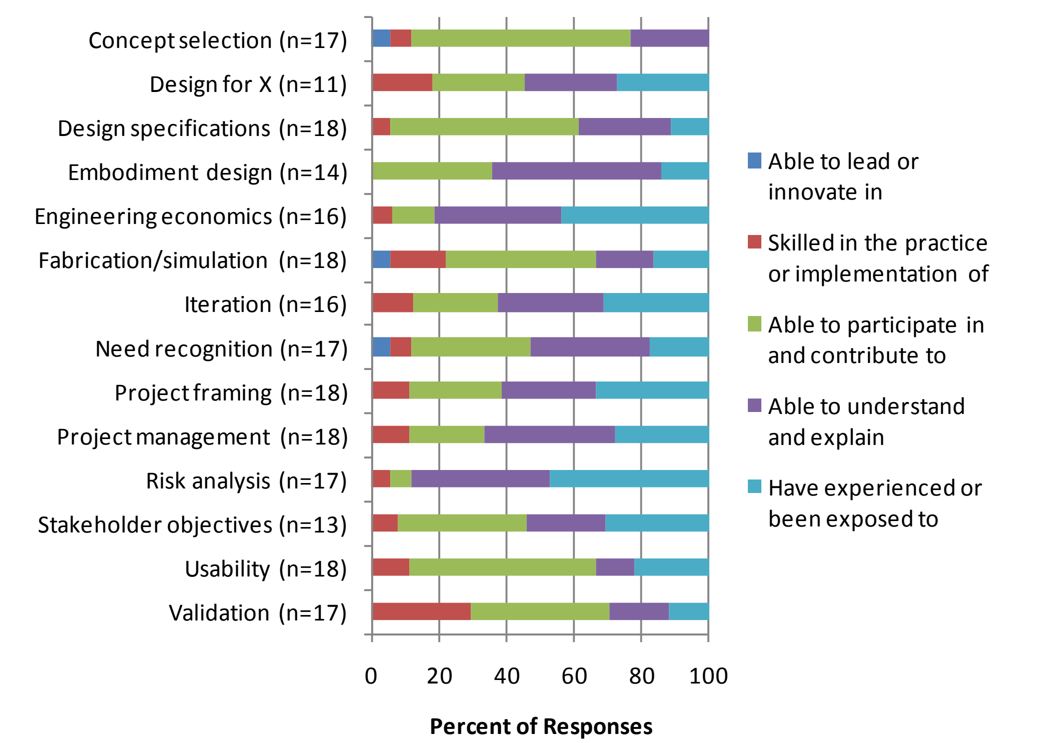


Figure 25a – Industry Expected Proficiencies
(Technical Topics)

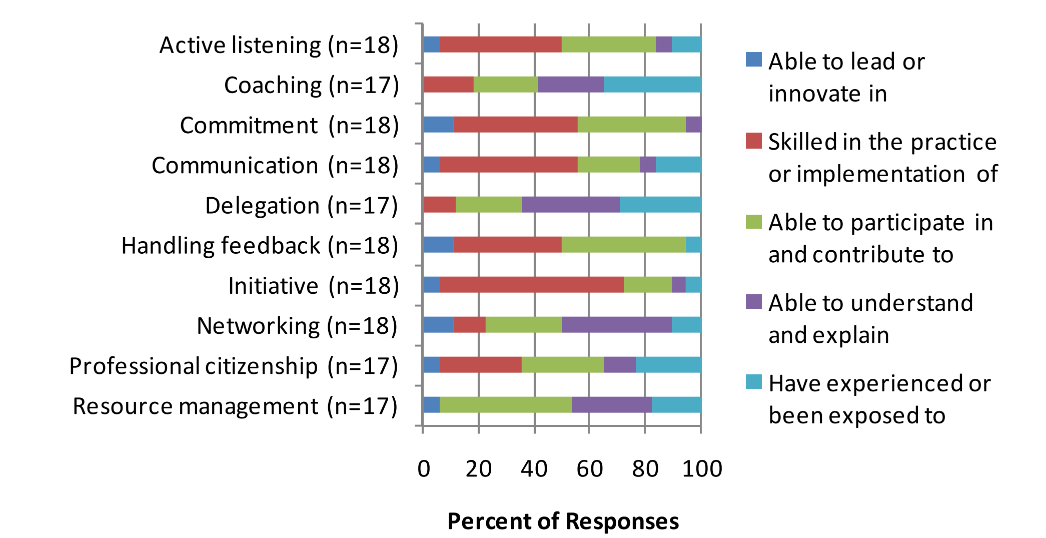


Figure 25b – Industry Expected Proficiencies
(Professional Topics)

Figures 26a-26b and 27a-27b show comparative proficiency levels (based on student self-perceptions and industry expectations) for two specific topics: fabrication/simulation and active listening. The pie-chart format exhibits the contrast in the data for the proficiency levels across student and industry respondents and across a technical topic and a professional one. Note that the student responses for both fabrication/simulation and active listening were fairly similar, whereas industry respondents expected higher proficiencies in the professional topic. Even more striking is the high level of proficiency perceived among students in contrast to the substantially lower expected level of proficiency by industry respondents. Indeed, industry does not often expect entry-level employees to be able to lead or innovate in these topics, whereas students perceive their ability to do so.

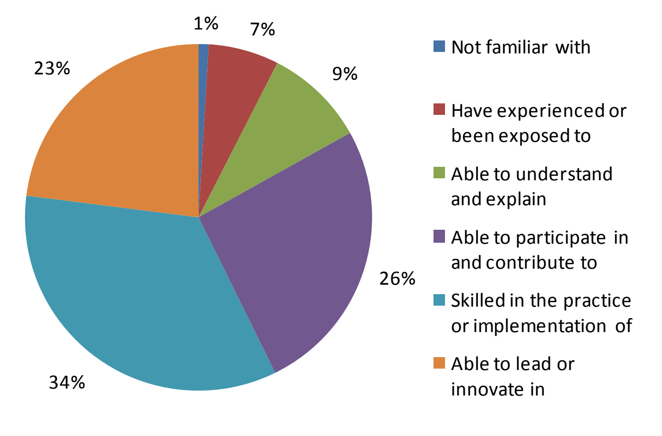


Figure 26a – Student Perceived Proficiencies for Fabrication/simulation (n=213)

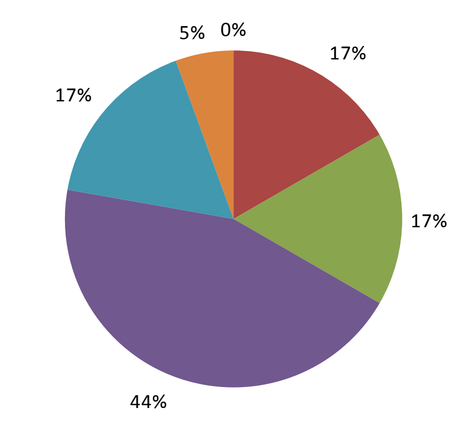


Figure 26b – Industry Expected Proficiencies for Fabrication/simulation (n=18)

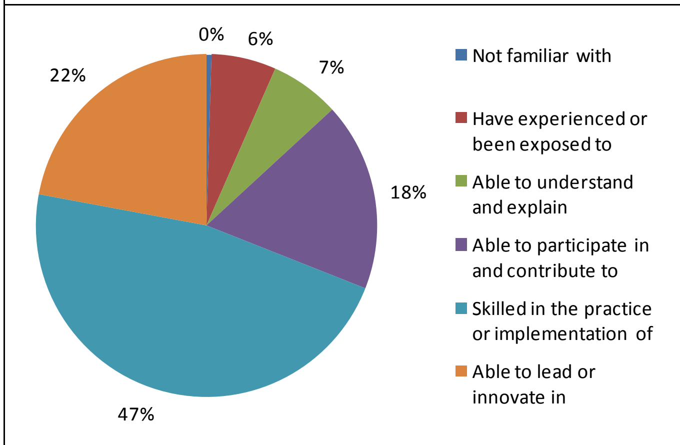


Figure 27a – Student Perceived Proficiencies for Active Listening (n=213)

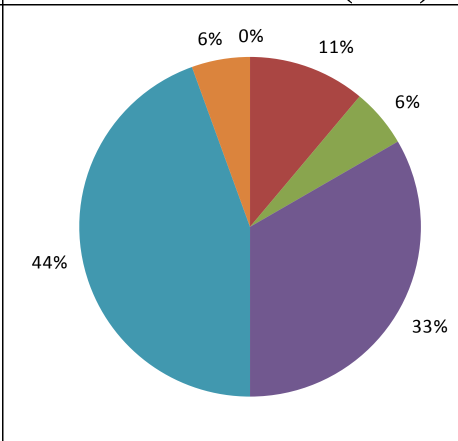


Figure 27b – Industry Expected Proficiencies for Active Listening (n=19)

The significance of these results is the mismatch between student perception and industry expectation: students have a more robust perception of their skills and abilities than industry expects. Additionally, the student perception is more general, balanced across both technical and professional topics, contrasted with industry's specific emphasis on proficiency with professional topics. The industry bias may be explained by the earlier comments that there is an expectation *a priori* of technical competence, while the ability to connect with one's professional environment defines employee uniqueness and value.

3E) Expected Course Outcome

Faculty and student respondents were asked to select all applicable outcomes expected for their capstone design course; industry respondents were asked to select all applicable outcomes/deliverables that entry-level employees should have experienced. The results of these expected outcome responses are shown in Figure 28. Note that the responses in each of the respondent groups sum to more than 100%, indicating that most respondents selected more than one response. Faculty and industry respondents are close in agreement that the expected outcome of the capstone course can be an analytical or demonstrated solution. In contrast, however, faculty expect that a usable, implementable or commercial solution is an expected outcome by nearly a three to one margin over industry. Student expectation, although fairly balanced across all three categories, is weighted toward a working demonstrable solution or usable, implementable, or commercial solution. The students are nearly equal with the faculty in desiring a usable, implementable, or commercial solution. Their matched response may reflect a desire in academia to produce a high-value solution, especially for externally sponsored projects, though it is interesting to note that industry does not expect as much.

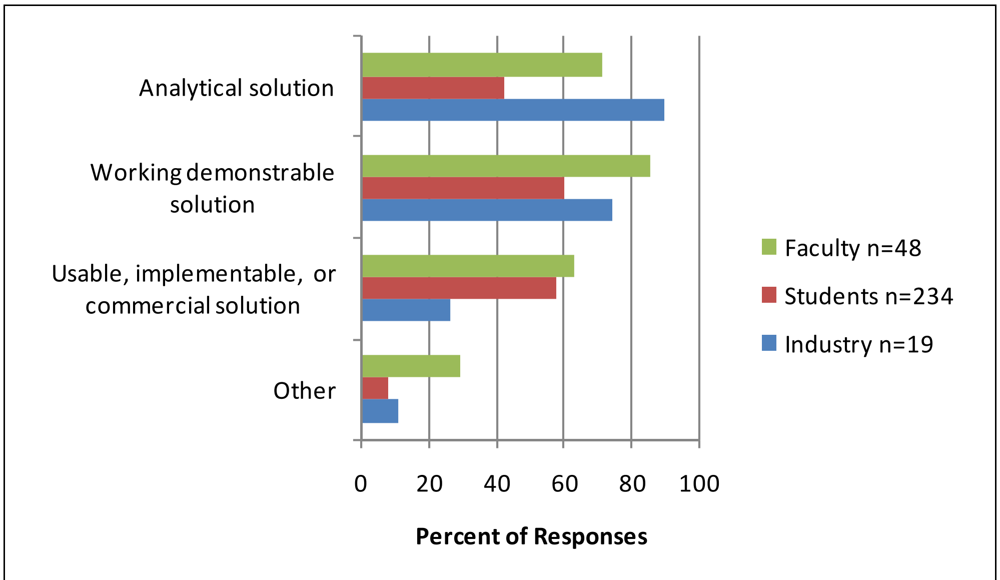


Figure 28 – Expected Outcomes of a Capstone Design Course

4. Conclusions

This pilot survey focused on content in capstone design courses: how that content is covered, how well students think they have learned the content, what content proficiency is expected of entry level employees, and how important the content is for student learning from the perspective of faculty, students, and industry employers. The study consisted of three surveys (one for each of faculty, students, and industry) about a specific set of 24 capstone course topics. Responses were received from 48 faculty (in 37 departments at 23 institutions), 240 students (in 34 departments at 21 institutions), and 19 industry employees, with each group representing CE, ChE, EE, ME, and general engineering. The 24 total academic institutions included a mix of public and private schools, with a wide range of sizes, degree and research levels, and geographic location across the U.S.

The survey results reveal consistent differences between faculty, student, and industry responses about importance, proficiency, and expectations, especially across technical and professional topics. Technical proficiency is fostered within academia, as this is most important to the faculty. This is not surprising given the academic objective of producing competent engineers within a discipline of study at graduation. That the expected faculty outcome for a capstone course is often a demonstrable or usable solution reinforces the emphasis on technical aptitude, as professional skills are buried in the process of achieving the outcome. From an industry perspective, however, the integration of professional and technical skills is vital, and professional skills themselves are fundamental to the success of employees. Industry's expectation for proficiency when placed in a time management context has a sense of vitality, i.e., in the capacity for survival, for a company unable to deliver its technical advantage in a timely manner will not survive. Students believe they are highly proficient in both technical and professional topics, while industry had more moderate expectations for entry-level engineers, with a stronger emphasis on professional aptitude. Interestingly, two-thirds of students noted having gained the professional proficiency at least in part in their capstone course, though faculty did not emphasize the material. Student perceived proficiency may be inflated compared to performance of entry-level engineers, at least in the eyes of these industry respondents, suggesting that students are evaluating their proficiency in the context of their more limited experiences. Overall, there exists a gap between industry expectations, student proficiency, and faculty emphasis.

The capstone course offers an opportunity to close that gap, especially if industry and faculty are knowledgeable of each other's perspectives and desires; professional skills are as critical as technical competencies. The best prepared students are self-aware of those skills they possess, those that they have mastered, and those that are escaping them, but required for future success.

5. Future Work

This paper provides a broad review of an extensive set of data generated by the pilot study. While this first look at the results reveals many interesting findings, additional detailed analysis is possible. Statistical analysis of selected questions may strengthen the initial conclusions discussed above. Additionally, an investigation of results from a given faculty member and his/her associated set of student responses would provide an in-depth look at specific capstone courses.

The results of the pilot survey are valuable in and of themselves, but another intent of the pilot study was to inform subsequent studies, especially with regard to study techniques and content. As such, future work includes more focused studies building on the results of this pilot in order to better understand and reduce the gap between faculty, students, and industry. Specific suggestions for this follow-up work are listed below:

- Entry-level Engineers: So as to address the influence of context and maturity, one focused study may also include entry-level engineers in industry with at least one year, but not more than three years, experience to determine their perceived proficiency compared to their levels as graduates.
- Baseline Technical Competency: Another important element is to identify a baseline definition of technical competency by industry and faculty, since this forms a starting point in evaluating current capstone practices and recognizing effective practices.
- Capstone Course Focus: To capture data specific to capstone courses themselves, future study questions could explicitly ask about what topics should be covered in a *capstone* course (as opposed to other places in the curriculum). Although the pilot study targeted capstone instructors and students, its questions asked about content with respect to student/employee learning and development in general. [Appendix B]
- Follow-Up Interviews: Future work would benefit from targeted open-ended questions to extract the subtle themes and to provide a better context of student, faculty, and industry perspectives and environments. Such questions might best be implemented as a semi-structured interview (in addition to, or in place of a larger survey) to elicit more detailed responses and enable the sort of dialogue not possible with the fixed survey instrument and larger sample size used in the pilot study.
- Modified Set of Topics: Future work may also focus on a modified set of topics, so as to address some that were not included in the pilot (such as concept generation and technical analysis), to remove possible overlap (such as in the problem definition category), and enable further detail (such as the distinction between written and oral communication).
- Previous Coursework: Since learning is not confined to the capstone course alone, however, additional future work could collect more specific data about the courses prior to the capstone experience, and to what extent they address both technical and professional content; when and where students learned technical and especially professional skills is of interest, as is the level to which faculty formally covered such material.
- Proficiency vs. Performance: Evaluating students' perceived proficiency is a first step in understanding what and how well students are learning, but assessing student performance (at the end of the capstone course) is more valuable. Completing such assessment consistently across multiple capstone courses, departments, and institutions will be a substantial challenge. Nevertheless, many companies evaluate their processes and outcomes through a maturity model with discrete levels (e.g., ad hoc, informal, formal and documented, mature, innovated), as with the Capability Maturity Model Integration for software[23]. Additionally, Six Sigma[24] is a disciplined, data-driven approach to eliminate defects and strive toward perfection in transactional, manufacturing, or design processes. These approaches to design in industry are intended to improve productivity in design and development projects. The authors hope to be able to determine a similar approach that would allow for the classification of design proficiency among capstone students. Student proficiency from an academic design program is ultimately evaluated by the attractiveness of the students to future employers. A maturity model – or other tool that is able to define a threshold and the requirements to

achieve it, then link expected proficiency to it – would provide a methodology to assist industry expectation and facilitate academic pedagogy. Like the output of an engineer's design efforts (a realization of the product requirements in a design that works and for which a customer will pay) the ultimate evaluation of student design proficiency is whether an engineering student upon graduation has the skills and abilities to produce working solutions, on which someone places value, to real problems.

The achievements that this overall effort desires to advance are three-fold: (1) identify the desired type and level of graduating student proficiency, (2) establish a measure to evaluate the ability of a capstone course to achieve this desired proficiency, and (3) identify and promote effective practices that contribute to achieving desired proficiency. This research is part of a larger effort to connect current capstone practices with student learning and achievement, so as to identify best practices and, ultimately, improve capstone education. The long term goal for this work is to produce engineers upon graduation with the appropriate skills for their chosen career path.

6. Acknowledgements

We extend our gratitude to the engineering faculty, students, and industry representatives who participated in this pilot study. We also acknowledge the attendees of the 2007 National Capstone Design Course Conference for inspiring this work and to the anonymous ASEE reviewers for their suggestions.

Bibliography

1. The Carnegie Foundation for the Advancement of Teaching. *The Carnegie Classification of Institutions of Higher Education*, http://www.carnegiefoundation.org/classifications/, accessed 17 March 2009.
2. Lang, J. and McVey, F. "Industry Expectations of New Engineers – A Survey to Assist Curriculum Designers", *Proceedings of the 1998 ASEE Annual Conference and Exposition*, ASEE, 1998.
3. Bankel, J., Berggren, K-F., Blom, K., Crawley, E., Östlund, S., and Wiklund, I. "The CDIO Syllabus: A Comparative Study of Expected Student Proficiency", *European Journal of Engineering Education*, Vol. 28, No. 3 (2003), pp. 297-315.
4. Kimble-Thom, M. and Thom, J. "Academic and Industrial Perspectives on Capstone Course Content and the Accompanying Metrics", *Proceedings of the 2005 Frontiers in Education Conference*, FIE, 2005.
5. Davis, D., Beyerlein, S., Thompson, P., Gentili, K., and McKenzie, L. "How Universal are Capstone Design Course Outcomes?", *Proceedings of the 2003 ASEE Annual Conference and Exposition*, ASEE, 2003.
6. Hines, P. and Christie, R., "A Capstone Design Project to Meet the Needs of the Changing Power Systems Industry and Satisfy New Accreditation Standards", *IEEE Transactions on Power Systems*, Vol. 17, No. 3 (2002), pp. 535-542.
7. Nixon, W. "The Use of 'Superclients' in a Civil Engineering Capstone Design Class", *Proceedings of the 2001 ASEE Annual Conference and Exposition*, ASEE, 2001.
8. Paulik, M. and Krishnan, M. "A Competition-Motivated Capstone Design Course: The Result of a Fifteen-Year Evolution", *IEEE Transactions on Education*, Vol. 44, No. 1 (2001), pp. 67-75.
9. Smith, R. and Eppinger, S., "Identifying Controlling Features of Engineering Design Iteration", *Management Science*, Vol. 43, No. 3 (1997), pp. 276-293.
10. Thigpen, L. and Glakpe, E., "The Capstone Design Experience in Mechanical Engineering at Howard University", *Proceedings of the 1999 Frontiers in Education Conference*, FIE, 1999.

11. Davis, D., Beyerlein, S. and Davis, I. "Deriving Design Course Learning Outcomes from a Professional Profile", *International Journal of Engineering Education*, Vol. 22, No. 3 (2006), pp. 439-446.
12. Mosborg, S., et al. "Conceptions of the Engineering Design Process: An Expert Study of Advanced Practicing Professionals", *Proceedings of the 2005 ASEE Annual Conference and Exposition,* ASEE, 2005.
13. Todd, R., Magleby, S., Sorenson, C., Swan, B., and Anthony, D., "A Survey of Capstone Engineering Courses in North America", *Journal of Engineering Education*, April 1995, pp. 165-174.
14. Howe, S. and Wilbarger, J., "2005 National Survey of Engineering Capstone Design Courses", *Proceedings of the 2006 ASEE Annual Conference and Exposition*, ASEE, 2006.
15. Shuman, L., Besterfield-Sacre, M. and McGourty, J. "The ABET 'Professional Skills' - Can They Be Taught? Can They Be Assessed?", *Journal of Engineering Educatio*n, Vol. 94, No. 1 (2005), pp. 41-55.
16. Aller, B., Kline, A., and Tsang, E. "Work in Progress: Improving the Senior Capstone Design Experience through Shared Perspectives and Best Practices", *Proceedings of the 2004 Frontiers in Education Conference*, FIE, 2004.
17. Bond, B. "The Difficult Part of Capstone Design Courses", *Proceedings of the 1995 Frontiers in Education Conference*, FIE, 1995.
18. Hopkins, D. "Roles of Project Teams and Venture Groups in New Product Development", *Resource Management*, Jan 1975.
19. Horenstein, M. and Ruane, M. "Teaching Social Awareness Through the Senior Capstone Design Experience", *Proceedings of the 2002 Frontiers in Education Conference*, FIE, 2002.
20. Kramer, K. "Partnering with Industry to Promote Ethical Business Practices in a Capstone Design Course", *Proceedings of the 2004 Frontiers in Education Conference*, FIE, 2004.
21. Kelley, R. and Caplan, J. "How Bell Labs Creates Star Performers", *Harvard Business Review*, Vol. 71 (1993), pp. 128-139.
22. Marin, J., Armstrong, J., and Kays, J. "Elements of an Optimal Capstone Design Experience", J*ournal of Engineering Education*, Vol. 88, No. 1 (1999), pp. 19-22, 129-130.
23. Chrissis, M.B., Konrad, M., Shrum, S. *CMMI®: Guidelines for Process Integration and Product Improvement,* Second Edition, Addison-Wesley: Reading, MA, 2006.
24. Reagan, L.A. and Kiemele, M.J. *Design for Six Sigma*, CTQ Media: Bainbridge Island, WA, 2008.

Appendix A – Glossary of Pilot Survey Topics

Active listening/hearing/understanding - a technique of focusing intentionally on who is speaking, whether in a group or one-on-one, in order to understand what the person is saying

Coaching/mentoring - the process of acting as a trusted counselor or guide, especially in an academic or occupational environment

Commitment and trust - a pledge to do something for another that both reinforces dependability and reliability and also demonstrates one's integrity, ability, and character

Concept selection - the process of evaluating the specific benefits or features of a design concept with regard to specified design criteria and identifying those design concepts or combination of concepts that are best meet the design criteria

Creation/construction/fabrication/simulation - the process of making or modeling a design solution for the purposes of evaluation or delivery to a client

Delegation - the act of assigning work to others and accepting work from superiors to optimize the efficiency of an organization by aligning tasks to the expertise of individuals or teams

Design for X (DFX) - Design for Excellence (DFX): a systematic approach to contemplate all relevant design considerations that may include manufacturability, reliability, maintainability, affordability, testability, etc., in the design process. For example, Design for Manufacturability (DFM), Design for Assembly (DFA), Design for Maintainability (DFMt).

Design refinement/iteration - the (often incremental) process of revising a design solution so as to better meet the determined design criteria.

Engineering economics - a subset of economics specifically applied to engineering problems; a design approach that treats costs as an independent design parameter, rather than an outcome

Handling feedback/constructive criticism - the ability to both receive and provide information to improve oneself or others

Initiative/ability to act - the proactive ability to begin and complete a task; readiness to take action when faced with a challenge or need of another

Multi-modal communication - communication using different strategies/methods (written, oral, visual, graphical, etc.); effective multi-modal communication involves the ability to identify and implement the optimal form of communication with another individual or group to exchange information and understanding

Need recognition - identification and understanding of the impetus behind the design problem to be solved, often expressed as a dissatisfaction with the current situation

Networking - a system of sharing information and services among individuals to determine common interest and linkage

Professional citizenship - the character of an individual as a member of his/her profession; the expected behavior, duties, obligations, and functions of a member of a profession to others in the profession and those whom they serve

Project framing/scoping - an investigation to determine the extent of the project, the activities/tasks that must be completed, the obstacles that must be overcome, and the limits required to successfully achieve the desired outcome

Project/design management - methods, techniques, tools, and processes used to define, manage, and audit a design project with respect to the people, team, objectives, and plans necessary to achieve the desired result

Resource management - the process of assembling and marshaling the necessary people, processes, funding, and schedule to achieve the desired results of the stakeholders

Risk/failure mode effects analysis - (RA/FMEA): techniques used throughout the design effort to identify and determine hazardous events and modes of failure that may affect a design and to evaluate the consequences of each

Stakeholder objectives - the set of desires and goals of the various parties who have an interest in and/or will be impacted by the design solution; these objectives inform the design criteria against which design options are evaluated

Synthesis/embodiment design - the creative enhancement approaches, methods, and techniques used within the structure of the engineering design process and the phases of problem solving to achieve a better outcome than by utilization of an ad hoc or trial-by-error process; this can be applied at a system, function, or detail level

Technical design specifications - detailed description of the features and performance characteristics of a design

Usability - a design perspective that focuses on user satisfaction and ease of use with respect to a product or design outcome; high usability implies the following: a) proficiency in use without outside assistance, b) efficient completion of a user task, c) enjoyment in use without frustration, and d) error recovery without outside assistance

Verification and validation - the process of conducting tests or evaluation strategies to determine that the design meets the specified design criteria informed by the stakeholder objectives

Appendix B – Pilot Survey Format and Questions

Section	Faculty	Students	Industry
1: Respondent Information	* Institution * Department	* Institution * Department	* Engineering discipline(s) represented by your industry:
2: Content/ Proficiency+	* Indicate the ways in which the following topics are covered in your capstone course. (Select all that apply: N/A, not covered, scheduled full class session, scheduled partial class session, just-in-time class session, assignment or project, reading or handout, informal out-of-class conversation, other) - Indicate the expected course outcomes. (Select all that apply: analytical solution, working demonstrable solution, usable/ implementable/ commercial solution, other)	* Indicate your level of proficiency with the topics. (Select 1: N/A, not familiar with, have experienced or been exposed to, able to understand and explain, able to participate and contribute to, skilled in the practice or implementation of, able to lead or innovate in) - Indicate which learning experiences contributed to your proficiency with the following topics. (Select all that apply: capstone course, previous course(s), internship or employment, other) - Indicate the expected outcome of your capstone course. (Select all that apply: analytical solution working demonstrable solution, usable/ implementable/ commercial solution, other)	* Indicate the desired level of proficiency for a new employee with an undergraduate engineering degree. (Select 1: N/A, not familiar with, have experienced or been exposed to, able to understand and explain, able to participate and contribute to, skilled in the practice or implementation of, able to lead or innovate in) - Indicate which expected deliverables/outcomes entry-level employees should have completed. (Select all that apply: analytical solution working demonstrable solution, usable/ implementable/ commercial solution, other)
3: Importance of Content	* Rate the importance of the following topics for student learning/ development. (Select 1: N/A, low, medium, high) * Of the topics you rated "high", please prioritize the three most important topics. (Select 1 for each: most important, second most important, third most important; N/A answer available for all.)	* Rate the importance of the following topics for your learning/ development. (Select 1: N/A, low, medium, high) * Of the topics you rated "high", please prioritize the three most important topics. (Select 1 for each: most important, second most important, third most important; N/A answer available for all.)	* Rate the importance of the following topics for new employee learning/ development. (Select 1: N/A, low, medium, high) * Of the topics you rated "high", please prioritize the three most important topics. (Select 1 for each: most important, second most important, third most important; N/A answer available for all.)

* = required question
\+ = response scales for proficiency questions were based on a previous study[3]

(Survey questions continued)

Section	Faculty	Students	Industry
4: Open-Ended Questions	- What aspects of your capstone course do you think best serve student learning and development? - Have you worked in industry? If so, where and for how long?	- What are your career plans after graduation? - How and to what extent did your capstone course prepare you for these career plans?	- What knowledge/ attitudes/ skills do you think are most evident in entry-level employees? - What knowledge/ attitudes/ skills do you think are most lacking in entry-level employees? - What knowledge/ attitudes/ skills does your company cover in trainings for entry-level engineering employees during the first year of their employment? - In Question 5, you identified your highest priority topics for employee learning/development. Why did you select these three topics? Please explain and/or provide examples of their importance.