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Student Reflections on Capstone Design: Experiences with Industry-Sponsored Projects*

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Students are a primary stakeholder in engineering Capstone Design courses, but the student voice risks being overlooked in discussions of Capstone Design pedagogy and development. While many engineering programs collect student feedback and performance data for accreditation purposes, the engineering education and engineering design literature provide few resources that capture student perspectives on Capstone Design, especially across multiple institutions. The 2012 Capstone Design Conference hosted two well-attended panel sessions called ''Student Reflections on Capstone Design'' specifically to highlight student experiences in Capstone Design courses with industry-sponsored projects. Each panel featured four different panelists who had recently completed their Capstone Design courses, had worked with different industrial sponsors, and represented different institutions and engineering disciplines. The facilitator of each panel asked the same initial questions of the respective panelists and then opened the conversation to questions from the audience. Although the trajectory of the two panels varied, content analysis of the transcribed discussions revealed similar themes from both groups. This paper addresses the analysis methodology, emerging themes, and sample reflections/suggestions from the student panelists. Discussion of the themes and student comments provides a foundation of student perspectives to aid faculty and industry liaisons in strengthening the Capstone Design experience.

Keywords: Capstone Design; industry sponsored projects; capstone pedagogy; student reflection; workplace communication

1. Introduction

This paper's purpose is to describe a range of student experiences during Capstone Design courses and student perspectives on Capstone Design issues. A wide-ranging literature review described below indicated that only 15 papers out of the almost 2000 reviewed were directly related to student input on these topics in industry-sponsored Capstone Design projects. Therefore, the information presented can be of great value to Capstone Design instructors as they work to improve their courses.

The experiences were gathered from two panels of students held during the 2012 Capstone Design Conference. The intent of the biannual Capstone Design Conferences is to share resources and ideas to improve Capstone Design courses and to build a community of faculty, administrators, and industry representatives involved in Capstone Design. The student voice is an essential element in such discussions, for students are a key stakeholder in the Capstone Design experience. The 2010 Capstone Design Conference piloted student contributions to the conference through a student panel about capstone pedagogy (the primary theme of the 2010 conference) and a poster showcase of student projects.

The 2012 conference followed a similar approach, but expanded to two student panels that captured student reflections about industry-sponsored projects during their Capstone Design experiences, thus connecting with the 2012 conference theme of industry involvement. The 2012 student panels were motivated by the recognition that Capstone Design instructors establish learning objectives and anticipated outcomes for capstone courses, but students may learn more from Capstone Design experiences than is documented in standard course deliverables/assessments.

The 2012 student panelists were selected from a list of current/recent students nominated by Capstone Design faculty to participate in the conference. The eight panelists (four per panel; a total of

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two females and six males) had recently completed their own Capstone Design course including industry-sponsored projects done in teams. Four students were in mechanical engineering, two in biomedical engineering, and two in general engineering, at seven different institutions. One panelist had taken a one-semester Capstone Design course, two panelists completed a two-quarter course, and four finished a two-semester course. Each panel included two panelists who had graduated within the past month, one panelist who was currently a graduate student, and one who had been working in industry for a year. The two panelists currently in graduate school brought the additional perspective of assisting with undergraduate Capstone Design as graduate students.

The facilitators for both panels asked questions from a pre-planned list and also facilitated questions from audience members. As such, the two panels built on the same foundation but followed different paths, given the interests of the audience members and the panelists. Facilitator questions addressed value of Capstone Design, preparation for Capstone Design, communication experiences, and lessons learned, among other topics. Both panels were audio recorded and these recordings are available on the 2012 Capstone Design Conference website [1].

2. Literature review

A wide-ranging literature review of over 1900 Capstone Design papers published between 1997 and 2012 was completed. Of this number, 300 were broader than or indirectly related to this paper's focus; those that referred directly to our purpose are described below. Some authors had gathered information from Capstone Design students working with industry-sponsored projects, or alumni who have done the same. In the literature, several approaches are described as a way of integrating the workplace into Capstone Design. Some studies describe imitating the workplace, perhaps by working on a faculty member's project [2, 3]. In another study, the communication instruction is based on workplace interviews with engineers, managers and executives; executives are brought in each semester to answer student questions about expectations for workplace communication [4]. The literature review showed a gap, however: to the authors' knowledge, no one has captured students expressing their experiences in Capstone Design from different angles.

2.1 Number of schools and disciplines

At most, each article reviewed reported on results from students in one university. Multidisciplinary teams were much more common than teams from a single engineering discipline [5–7]. Some of the multidisciplinary teams combined Technical Communication or English with engineering disciplines such as Industrial Engineering and Mechanical Engineering [8–9]. Other teams included five different types of engineering disciplines, [10–13] for example, mechanical engineering, electrical engineering, computer systems, industrial engineering, and biomedical engineering [13].

2.2 Number of respondents

In many cases, authors did not include information about the number of respondents [7–11]. But in others, the range of undergraduate students involved was eight to 150 [4–6, 11–14]. The range of alumni (graduating over a span of 10 years) ranged from 21 to 397 [12, 15].

2.3 Methods used to gather data

Authors reported collecting data with five different methods. Surveys, including open-ended questionnaires, anonymous web-based surveys [11], and student evaluations of the course or the instructors, were the most common. In one article, ''not all surveys were fully completed'' [15, p. 5] so the authors decided to categorize the comments into themes and then use that data to help incoming students be successful and to help make improvements to the course. Student exit interviews—the only approach conducted in person—were reported in two articles [9, 10]. One set of authors required end-of-semester reflective memos [13]. Still others asked no specific questions of students [8], and sometimes students were asked only to rate other students [7].

2.4 Research intent

Researchers gathered data for a number of different purposes. Sometimes the focus was on a specific topic such as the project bidding process [12], teamwork [9], or ''how the course helped [the student]'' [14, p. 4]. In other articles, the emphasis was on quality mentoring from the sponsoring organizations [11] or the faculty's technical expertise [6].

In several articles the orientation was broader. For example, in Wall's 1997 study, the purpose was ''to examine the value of working with industry and to look for ways to improve the program'' [5, p. 1]. In Halvorson's 2009 study, alumni who already took Capstone Design were asked to identify the most difficult challenges, and to spell out ''the recommendations [they had] . . . for helping new students do well in capstone'' [15, p. 4].

In many articles, the specific questions asked of the subjects were not specified. Several examples of questions that were used included, ''Please identify

the skills used in industry that you learned in Capstone Design'' [5], ''Please identify the areas of Capstone Design that need improvement.''[5], as well as ''What was your most difficult challenge in Capstone Design?'' [15].

2.5 Research outcomes

Authors of focused studies reported specific outcomes from their research. For example, Rutar [16] concluded that ''student interest and motivation in a project typically varies throughout the year.'' Schmidt [11] found that ''sponsoring organizations were communicating in a timely manner, with complete responses that were helpful.'' Types of communication in this study included e-mail, single user phone calls, and conference calls. Somerton [6] reported that 15 of 19 teams used the technical talents of other faculty members.

Authors of broader studies also reported a range of findings regarding student perception and reflection that contribute to the body of knowledge in Capstone Design. Selected findings are noted in Table 1.

Students across articles mentioned the following areas as those needing more support in Capstone Design courses: new technology, maintaining timelines, more time with faculty, teamwork, project ambiguity, project and time management, and ''more constructive feedback and encouragement from sponsoring organizations'' [11, p. 17].

2.6 Extension of literature

The 2012 Capstone Design Conference student panels extended the work already reported in the area of industry-sponsored projects by 1) expanding the number of universities represented from one to seven schools in a variety of geographical locations, 2) capturing in-person interaction with other student panelists and an audience of faculty, industry representatives, and students interested in Capstone Design, and 3) conducting a primarily qualitative study. The second and third characteristics were unreported in the literature.

3. Methodology—textual analysis of panelist responses

The approach used for analyzing the two student panels followed a classical content analysis methodology [17]. A total of three hours of recorded panel discussion was manually transcribed yielding 168 unique textual reflections from the student panelists. Each individual textual contribution was reviewed and interpreted by four independent analysts (authors) and then coded into content themes. Collectively, the content themes were reviewed by the four analysts and a meta-thematic framework with eleven individual themes was developed: applying prior (and new) knowledge, capstone curriculum, communication/documentation, expectations, industry context, interaction/relationships, job/recruiting, multiple solutions, preparation for capstone, teamwork, and timelines/project management. As validation of the meta-thematic framework, a computer-based content analysis program (QDA MINER) was used to corroborate theme generation. This program generated a frequency analysis of word and phrase counts from the transcribed discussions. No changes were made to the theme categories generated by the authors as a result of the computer analysis.

To assure inter-rater reliability and objectivity in the assignment process, each analyst independently assigned the original 168 textual reflections to the eleven themes in the meta-framework. Here, analysts could assign individual reflections to multiple themes if applicable. Using Landis and Koch's Kappa Benchmark Scale, a kappa statistic of .87 was calculated. According to Landis and Koch's scale, a statistic in excess of .81 indicates ''almost perfect'' agreement among the raters [18, p. 125]. In the few areas of disagreement, the four authors collectively discussed these differences to achieve consensus. In the final round of investigation, a total of 272 assignments were made, with some reflections placed under multiple themes.

Figure 1 provides an overview of the meta-frame-

Table 1. Research Findings from Broad Studies

Research Finding	Citation
Students (in multidisciplinary teams) mention a new understanding and respect for those outside their disciplines, and the importance of each discipline's contribution to a successful project.	[8, 9]
Students reported that teamwork and communication are skills used in industry and learned in Capstone Design. ''By working with industry students got a real hands-on experience.''	[5, p.4]
Students noted being taught the ''politics of getting a project done within an organization.''	[10, p.7]
Many students point to a direct correlation between work in this class and job or internship offers from employers.	[8]
Students reported a broader understanding of what it takes to become a successful engineer, including communication, an understanding of team management, and systems and other engineering knowledge.	[9]
In the end-of-semester reflective memos, the topics stressed with the highest frequency were ''1) design process, 2) teamwork, 3) communications, [and] 4) technical knowledge''.	[13, p.13]

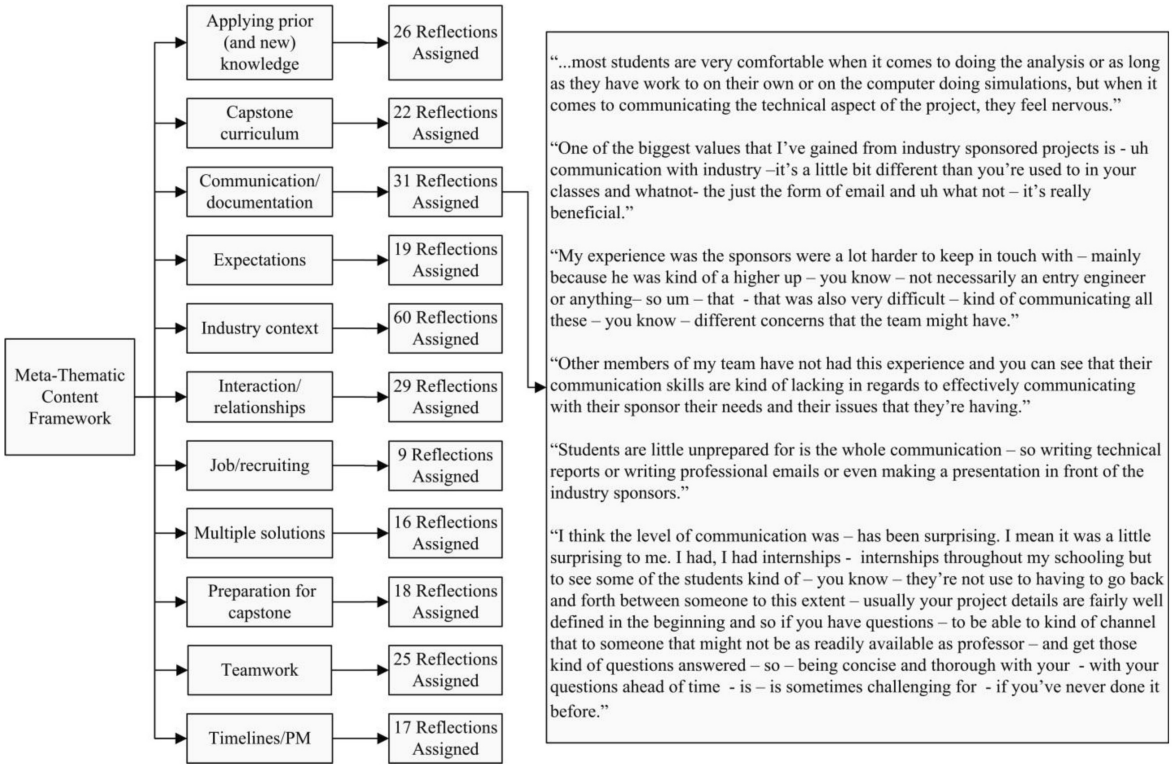

Fig. 1. Meta-Framework for Content Analysis: Student Reflections on Capstone Design.

work showing the number of textual reflections in each content theme. As is seen in Fig. 1, textual reflections varied from 9 for the Job/Recruiting theme to 60 for the Industry Context theme. For the Communication/Documentation theme, several examples of verbatim reflection are provided.

4. Results and discussion

This section addresses the key points from the two panel discussions, sorted into the 11 categories depicted in Fig. 1. Note that all quotations and paraphrased comments from the panelists reflect the panelists' own experience or that of their team members in Capstone Design. As such, the comments below are not intended to necessarily represent the perspective of every Capstone Design student. The recommendations provided by the panelists are addressed to faculty, industry representatives, and future Capstone Design students.

4.1 Applying prior and new knowledge

Applying their knowledge to their team's project, the panelists said, was difficult. For example, one panelist commented, "When we started off, we didn't really have any direction to go . . . for a while, our main issue was just choosing a problem—it took us a while." And, if the sponsoring organization had no liaison engineer, then the Capstone Design students needed to apply the engineering information they acquired in other classes. Many panelists discussed dealing with future unknowns. They made three recommendations for Capstone Design students: 1) use critical thinking by coming at the problem from a different angle, 2) teach yourselves the information you need to know, and 3) reach out for information—for example, by asking "the machine shop guys."

4.2 Capstone design curriculum

The panelists discussed the category of the capstone curriculum in great length, with comments on the themes of how student groups choose their projects, how Capstone Design is different from other prior courses, whether communication advice is needed, and whether lectures and self-teaching are both an important part of the course. Student groups were often selected through a bidding process, which was harder if the team was multidisciplinary. Sometimes student teams had to explain why they would be qualified for a certain project but they didn't always get the project they wanted. Overall, most of the student panelists preferred capstone teams working on different projects rather than all teams working in competition on one project.

The student panelists also pointed out that Capstone Design is different from other prior courses

because students have more responsibility and more difficult work. They described the work as more important because "you can actually go out there and use that knowledge to actually build a real project that somebody's going to use." Finally, panelists agreed that both lecture and self-teaching are important. They suggested faculty provide optional separate customized lectures, such as one on patents, for Capstone Design students.

4.3 Communication/documentation

The panelists spent a great deal of time discussing communication in Capstone Design. According to the student panelists, Capstone Design students are unprepared for, surprised by, and uncomfortable with the level of communication required in Capstone Design. The panelists' noted that if a student is in a team with some members who have never interacted with industry, it shows: such students "lack the communication skills with regard to effectively communicating with their sponsor" (for example, in emails) with respect to their needs. Students are unprepared for the required communication, including writing professional emails, writing technical reports, making presentations in front of industry sponsors. The panelists admitted to being surprised at how prepared they needed to be when presenting to clients. For example, teams needed to "submit their final presentation . . . at least a week before it was due just so they [the client] could look it over . . . we were a little unprepared for that."

The panelists also noted that in their experience Capstone Design students were not used to the extent of communication in industry, especially back-and-forth communication with their liaisons. The panelists recognized that communication with industry must be concise, and is more effective if students group their questions for their liaison. The panelists remarked about learning to cc or bcc supervisors and other involved in their projects so people are more aware of their responsibilities (for instance, needing a timely signature on documents needed by the team.)

Panelists recognized that a common component of Capstone Design is student presentations including questions and answers to other teams, faculty, and sponsors, which were also useful for workplace training. Panelists also stressed that Capstone Design students need communication advice, such as "the number of pictures used in PowerPoint", as well as technical advice.

4.4 Expectations

The panelists' responses to expectations from/in Capstone Design fall into three categories: 1) faculty expectations of students, 2) student expectations of faculty, of industry, and of themselves, and 3) industry expectations of students. The panelists noted that faculty cannot expect the students to be experienced in solving real-world problems like they face in Capstone Design. The panelists expected to have to manage their liaison's demands, but they would have liked their faculty's help with this. One panelist pointed out that at times the course director could have stepped in to say "you know the boundaries are a little bit blurry, but you still need to make sure that [your request] is within reason." In addition, panelists noted that industry's expectations of students could be new or different, such as sponsors wanting weekly progress reports. Based on their Capstone Design experience, panelists concluded that students tend to do just the amount of documentation expected by industry: if their sponsor expected less, the team did less.

4.5 Industry context

Many comments on the category of Industry Context were included in the student panelists' discussion. These comments can be grouped into five major subcategories, as discussed below.

4.5.1 Use of deliverables in the real world

Panelists reported that sometimes in Capstone Design, "what we developed wasn't a standalone device; it was meant to be included in their [the company's] existing product, which had its own unique challenges." In one example, a panelist had to take into account the harsh electromagnetic environment in which the product would be used at the sponsor's site. Because there are so many variables involved in an industry project, students have to plan sooner in the process than later.

4.5.2 Seriousness of Real-Life Engineers

Panelists reported learning that real-world engineers are "very serious" and that when students work with real companies, the group has real-world deadlines.

4.5.3 Teamwork as preparation for the workplace

According to the panelists, being assigned to a team was a more realistic and good experience since it is more like the process used in industry. As they indicated, "this is reflective of what you're going to see in the real world if you're in a team environment." The collaboration required in working on a team, especially a multidisciplinary team, matches the company's own teams.

4.5.4 *Effect of liaisons*

Student panelists reported the company liaison can be a major asset to a Capstone Design team: company liaisons can be real partners in a Capstone Design project. They can "strongly motivate the student group, help design the review, and even help with the machining".

4.5.5 *A Taste of the real world*

Working with industry, the panelists said, provides students with "a taste of the real world . . . Students often get to know a product line, a company, and its engineers".

The student panelists noted several concerns and suggestions regarding working with industry. In particular, the panelists found that sponsors were often not familiar with all the tools and software that the students have available to them. In addition, some panelists felt that industry sponsors limited the scope of the project too much, so panelists suggested that the university inform the liaison in advance what is expected during the project.

4.6 *Interaction/relationships*

Panelists commented on interactions with both sponsors and faculty during Capstone Design. They suggested interacting with both the sponsor's direct contact or liaison and their superiors to keep everyone in the loop. For instance, one panelist described an issue faced in Capstone Design:

> *. . . we had our direct contact that we spoke with . . . multiple times a week, sent emails back and forth . . . we visited him a number of times. And [at the] beginning of the second semester we found he wasn't relaying that information to his superiors, so his superiors . . . [thought] we weren't doing any work . . . during the full first semester. They didn't think we had even visited the company, so there's a little bit of a backlash there in the beginning of the second semester with them.*

Panelists reported surprise regarding the availability of their faculty and their liaison, recognizing that neither was as available as the students expect. One panelist suggested "of course . . . [faculty] should always have the door open." Panelists also noted that students relied on their faculty for technical advice as well as teammate problems that the team could not solve. Panelists acknowledged that interactions with sponsor liaisons or other external contacts may be difficult for some Capstone Design students. "If you have questions . . . for . . . someone that might not be as readily available as your professor . . . being concise and thorough with your questions ahead of time is . . . sometimes challenging if you've never done it before."

4.7 *Job recruiting*

The positive relationship between Capstone Design and job recruiting resonated in both panels. Panelists mentioned that by working with industry, students get a good feel for what a certain company is about. Conducting Capstone Design projects helped some panelists get jobs, and students used their presentation training to develop and give talks that were part of the recruiting process. One panelist reported the following experience:

> *When I was interviewing for this program, for the job that I'm in now, there's a three-day long assessment center and they gave us a surprise case study at the end that we had to prepare all night. And, I actually used every single thing from my senior design course in my presentation: Gantt charts . . . everything and they said it was the best presentation they had ever seen.*

4.8 *Multiple solutions*

A number of panelists pointed out that students in Capstone Design are not limited to one solution, unlike in their previous courses but similar to industry. In industry, there is "no such thing as a right design or a wrong design". Panelists commented that in other classes they are given steps that lead to one answer, but Capstone Design required a more open-ended approach. "Another benefit is learning to critically think—a lot of times in school you have textbooks and you have these questions that has a set answer . . . on this project . . . I learned . . . how to critically think . . . just look at things from different angles and not limit ourselves to one solution."

Panelists also remarked on the large number of last-minute changes occurring in an industry-sponsored project, recognizing that things may be very different at the end of the project than they were earlier. For example, one panelist reported "last minute changes that you . . . don't really account for: our compressor didn't fit through the door." Panelists noted that sometimes Capstone Design students even have to backpedal and start over, or replan the work they have already completed.

4.9 *Preparation for capstone design*

Both panels addressed the preparation students need for their Capstone Design courses. Panelists indicated that students first taking Capstone Design are not aware that they will be dealing with future unknowns. To solve their problems, they will need to 1) research topics not taught and 2) rely on prior coursework. Panelists suggested students would benefit from taking the most relevant courses, such as MATLAB, just before taking the Capstone Design course.

Panelists indicated that students in Capstone Design were comfortable with engineering skills,

but less comfortable with professional skills. Students in both panels suggested topics for pre-Capstone Design courses: 1) design, 2) team-building, and 3) awareness that real-world problems usually have more than one right answer. They also implied that communication instruction would be helpful.

4.10 Teamwork

When asked about teams, the students in both panels focused on how to decide responsibilities for various team members. They suggested students in the team focus on where their skills and areas of interest lie. In a real-world team environment, if the team fails, every member is responsible. As a panelist noted: "what you're going to see in the real world if you're in a team environment and your team fails . . . you can blame other people for it, but it's not going to be favorable for anyone, so . . . you have to succeed as a team."

Panelists reported that team leaders were selected in a variety of ways, with team members deciding on one of the following strategies: 1) have different people in charge of different areas such as communication with the faculty advisor and communication with the client liaison, 2) have rotating leaders, and/or 3) let their leader gradually emerge. Panelists remarked that students don't like having a leader assigned by the faculty but this situation often occurs in the workplace so it is good preparation.

Panelists offered that communication in teams is important especially when the team lets their leader emerge and particularly when giving feedback to each other. To find out if a member of a team is a "slacker", panelists suggest faculty requiring all team members to contribute to class presentations, especially during the question and answer segments. To get a slacker to participate more, the panelists recommended either 1) the team leader speaking directly to the "dead weight" to get them to step up, or 2) figuring out what the slacker likes to do and assigning them tasks in that area. And the panelists also noted that Capstone Design students are unprepared for working in multidisciplinary teams; for example, team members find it difficult to estimate the time required for other types of engineers to perform their tasks. However, panelists indicated that working in a multidisciplinary team is a "positive opportunity", since most workplace teams are composed of different types of engineers.

4.11 Timelines/project management

Panelists reported that students needed to estimate the time required for different parts of their projects. In the particular case of interacting with their liaisons, panelists usually expected to hear a response from the liaison before they actually did. Panelists recommended varying the types of checkpoints for different projects (for example, not every project necessitates a physical prototype). They pointed out that the checkpoints should be rigorous such as the set of guidelines that "I hated . . . while we were doing it, but . . . looking back at it, it was very helpful." Finally, the panelists suggested that "the more [the faculty] kind of force [the students] to have these rapidly approaching deadlines . . . [the better, since] you can't really teach people to . . . be ahead of schedule; be on the ball, that's something they have to kind of figure out how to learn."

5. Conclusions and implications

The two panels entitled "Student Reflections on Capstone Design" at the 2012 Capstone Design Conference provided a window into student experience in and takeaways from industry-sponsored Capstone Design projects. Each panel included four panelists who had recently completed Capstone Design; collectively the panelists represented seven institutions and three engineering disciplines. Qualitative analysis of the three hours of panel recordings generated 168 distinct textual reflections that populated a framework of 11 different primary themes: applying prior (and new) knowledge, capstone curriculum, communication/documentation, expectations, industry context, interaction/relationships, job/recruiting, multiple solutions, preparation for capstone, teamwork, and timelines/project management. Panelists also offered suggestions to faculty, industry liaisons, and future Capstone Design students. The consistency of the reflections across the two panels (despite different panelists and audience prompts) is a testament to the similarity of experience across institution and discipline, underscoring the relevance of the comments to a wide range of Capstone Design courses.

Although many Capstone Design faculty assess student learning through a variety of assignments, the body of literature capturing student reflection and feedback on Capstone Design is strikingly limited. Given the important role students play in Capstone Design, their voices must not be overlooked. Students experience Capstone Design through a lens different from that of faculty or industry liaisons; their reflections on this experience are valid input to improve Capstone Design for all involved. Capstone Design faculty and industry liaisons are encouraged to solicit and absorb student and alumni input especially outside of formal Capstone Design deliverables, such as through informal conversation and focus groups, at panels at regional and national conferences, and through further studies across institutions.

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