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Managing and Mentoring Capstone Design Teams: Considerations and Practices for Faculty*

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This paper presents the findings from a panel session at the 2010 Capstone Design Conference in Boulder, Colorado in which panelists and participants had a lively discussion about practices associated with managing and mentoring student teams. The three broad topics discussed at the session were the methods of assigning teams, product versus process learning objectives for design teams, and non-technical aspects of team performance (e.g. race and gender dynamics, professional and interpersonal communication). For each topic, the paper describes the wide variety of views and approaches (some contradictory) that were explored regarding each topic, as well as the factors affecting choice of approach. In addition, the paper highlights three themes that recurred across the topics: 1) clear learning objectives for capstone or any project-based activity are central to effectively designing and mentoring teams; 2) faculty participants do care deeply about their students and take steps to act in ways that benefit students, and 3) both positive and negative aspects of student attitudes and behaviors may reflect faculty attitudes and behaviors, implying that we should examine and act to improve our departmental cultures if we hope to affect student performance. The results of this discussion point strongly to the need for more research on teaming in capstone courses to better understand the relationships among curricular environment, student development, and learning outcomes.

Keywords: capstone design; student teams

1. Introduction

Capstone projects are ubiquitous in the United States and, increasingly, around the globe as a result of both ABET, Inc. accreditation requirements and the strong sense among educators and industry stakeholders that students need such experiences. Capstone projects, as well as design projects across the curriculum, provide important sites for students to integrate sometimes disparate components of technical knowledge together in, as specified by ABET, Inc., 'a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints.' [1] These projects serve as sites not only for the integration of knowledge, but also for the development of a variety of professional skills, including teamwork. Some of this emphasis results, no doubt, from the inclusion of teamwork in the ABET-defined student learning outcomes, but as Dym et al. point out in their 2005 review of design education, engineering design is almost always, by its very nature, a team activity in which participants engage in social negotiation of multiple points of view [2].

A number of national surveys attest to the widespread use of student teams in capstone courses and describe patterns that have remained constant over the past 15 years. Todd et al. conducted the first survey in 1994 to generate benchmarks for improving the capstone course at their home institution [3]. Howe and Wilbarger conducted a follow-up survey in 2005 to assess the trends across the decade [4], while McKenzie et al. conducted a 2001 survey focused solely on assessment practices within the course [5]. Finally, in 2009, Pembridge and Paretti conducted a follow-up to Howe and Wilbarger that extended work on course structure to include faculty beliefs and teaching practices [6]. Across these surveys, patterns over the past fifteen years have remained consistent with respect to team structures: team sizes of 4–6 dominate, most courses assign only one team to each project, and faculty typically both provide in-class time for teams to work together *and* expect teams to meet regularly outside of class [6]. At the same time, while project planning and management has consistently been

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among the top five topics covered in the course, teamwork has not [6] (though it may be a tacit component of project management).

Thus while team structures dominate capstone courses, survey data suggest that teamwork itself is not a dominant subject for instruction. In addition, the 2010 survey results indicate that only about half of the faculty respondents reported including 'quality of teamwork' in their evaluation of the final grade, although 2001 data suggests that more than half of the faculty respondents considered 'the ability to function on multi-disciplinary teams' an appropriate area of assessment in capstone courses [5]. It is not surprising then, that approaches to evaluating teamwork in capstone courses have begun to emerge in recent years [7–10]. At the same time, capstone design research has begun to draw on the literature surrounding team formation to develop more robust approaches to creating capstone teams [10]. The results of work in these areas include publicly available team formation and assessment tools from both the Transferable Integrated Design Engineering Education (TIDEE) project (http://www.tidee.org/page/Front) and the Comprehensive Assessment for Team-Member Effectiveness (CATME) project (https://www.catme.org).

Such tools represent critical advances in our approach to teamwork in capstone courses, but a number of questions remain in terms of faculty's responsibilities with respect to the development of students' teamwork skills across the duration of the project. Unfortunately, as Shuman et al. note in their review of professional skills in the engineering curriculum, 'too often educators incorporate student teams into their courses with little thought to their best use. Minimal guidance is provided to students on group development, soliciting member input, consensus building, resolving conflict, and team leadership' [11]. Despite advances in certain areas and numerous anecdotal reports in conference papers, much work remains to be done regarding how faculty approach the teaching and learning of teamwork in capstone courses.

In this paper, we begin to bridge this gap by synthesizing salient positions around this issue as they developed from a panel session led by the authors and engaging several dozen participants at the 2010 Capstone Design Conference. In particular, the synthesis addresses three primary questions:

1. *Self-selection versus systematic assignment of teams*: When creating student teams, should faculty allow students to select their own teams to maximize student satisfaction or assign teams based on a systematic procedure (e.g. grades, personality types, team behavior)?
2. *Product versus process*: In capstone projects, should faculty be more concerned with a team's ability to create a successful product or with students' ability to learn how to work effectively as a team as evidenced by a systematic process?
3. *Technical practice versus professional practice*: When mentoring student teams, should faculty be concerned only with teams' ability to deploy technical knowledge effectively to solve the problem, or should they also address professional issues surrounding team dynamics, including gender, race and ethnicity, and communication and interpersonal skills?

The audio recordings of the panel session were analyzed to identify recurrent themes; themes were identified based on multiple occurrences of related statements as well as length or depth of discussion and dialogue around a particular point. Detailed qualitative coding is outside the boundaries of this work and is of limited value in this context given the nature of the panel discussion and the role of the moderator in shaping the discussion and moving the session forward; moreover, this data was not collected via a systematic process of qualitative inquiry and the results reported here are primarily anecdotal accounts provided by a self-selected group of participants.

As the following sections demonstrate, although we posit these questions as either/or, the answers offered by faculty participants and the resulting discussions suggest that experienced faculty tend to adopt a both/and approach, with multiple factors influencing the balance in each case. In seeking to negotiate the two poles in each question, capstone faculty systematically reflect a strong desire to prepare students holistically for professional practice, and factors such as the desired learning outcomes of the course, the constraints of project sponsors (industry or faculty), and the trajectory of the curriculum leading to the capstone experience all play a role in shaping the ways faculty manage and mentor student teams.

The results of this session define the set of core questions that face capstone faculty and set an agenda for future research on the teaching and learning of teamwork in capstone courses. Table 1 summarizes the major challenges and research questions associated with each of the three major themes. The subsequent sections develop these ideas in detail.

2. Self-selection versus systematic assignment of teams

Of the three primary questions posed by the panel

Table 1. Summary of major themes, challenges, and potential research questions

Theme	Challenges	Potential research questions
Self-selection versus systematic assignment of teams	Aligning selection approach with learning objectives. Creating well-balancing teams. Providing learning opportunities while emphasizing team performance. Accounting for schedule compatibility. Accounting for student interest by project.	How do we negotiate teaching students that difference is not negative but instead can be productive to team dynamics? How do we balance methods for constructing effective teams (e.g. through personality tests) with students' right to privacy? How do students best learn to be effective team members? What is the state of faculty member preparation for managing small group dynamics?
Product versus process	Aligning learning objectives with project goals and expectations of project sponsors. Accounting for curricular scaffolding. Managing time constraints. Defining success criteria. Including 'real world' attributes while providing a supportive learning environment.	What degree of team and design knowledge do students need before product should become a dominant criteria? How can teams be mentored to best help students learn effective, transferable processes? How does an emphasis on process affect students' ability to engage in successful design? How does an emphasis on product affect students' ability to develop as effective team members?
Technical practice versus professional practice	Aligning learning objectives with teaching opportunities and expertise. Developing strategies to effectively discuss race, ethnicity, and gender in engineering teams. Integrating communications learning with other capstone team objectives.	Although some research already exists, many questions remain about the impact of diversity issues on both team performance and individual student learning outcomes. What approaches are best suited to helping faculty effectively engage issues of diversity in team mentoring? How are those affected by the overall demographics of the student population? What strategies can help faculty effectively and practically integrate communication into capstone courses? What approaches help build partnerships with communication faculty? What helps faculty develop the ability to teach communication? How does the balance between technical and professional skills affect student learning? What learning outcomes are most appropriate for the course. What characterizes an exemplar? What strategies are effective in changing the culture?

session, the question of team assignment is the one most addressed by robust research both inside and outside engineering. Literature identifies three basic methods of assigning teams that instructors commonly use: self-selection, random assignment, and systematic instructor assignment, each of which has been used in capstone courses based on a variety of factors.

Self-selected teams give students more responsibility and control over their learning experience than when instructors assign teams, which has both advantages and disadvantages [12]. Advantages include increased group cohesiveness [13–16], accountability [17], and cooperativeness, which increases team members' feelings of indispensability and improves their satisfaction with deadlines [18]. In contrast to these findings is considerable evidence of negative effects associated with self-selection. Feichtner and Davis reported that self-selected teams resulted in 40% of students' worst group experiences and only 22% of their best group experiences [19]. In a study of engineering students at the United States Military Academy, Brickell and colleagues found that self-selection had negative effects on students' opinions about the course, instructors, projects, classmates, and other criteria [20]. Self-selection can lead to excessive homogeneity, such that teams lack diversity [21–22] and might not have all the skills required for their team's task [17]. Self-selection can also lead to clique behavior that erodes team cohesion and performance [23].

Random assignment is another option for assigning teams, but this method has a number of disadvantages and no clear strengths relative to the alternatives. Random assignment does not necessarily result in a team with any more diversity, balanced skills, or blend of personalities than does self-selection [24–26], yet it raises concerns about fairness [27]. Bacon and colleagues found that randomly assigned teams were negatively associated with students' best team experiences, and were not significantly associated with students' worst team experiences [27].

Instructor-assigned teams enable instructors to control various criteria in an effort to create positive team experiences, and the preponderance of the available evidence suggests that controlling those criteria improves student outcomes [28]. Although there are clear advantages to assigning teams according to certain criteria, instructors assign teams relatively infrequently because the logistics can be challenging [27, 29]. The complexity of team-assignment increases dramatically as the class size and number of variables to be considered increases. Therefore, implementing more than a few criteria for team formation can be inordinately time-consuming for instructors, especially when accounting for students' availability for team meetings outside of class and when working with the large classes that are typical in undergraduate engineering. However, web-based tools are now available that can help instructors assign students to teams quickly while optimizing the degree to which all teams meet the instructor's team-formation criteria [10].

2.1 Panel perspectives: synthesis of the discussion

The personal experiences described by the participants echo many of the themes expressed in the teaming literature. Many participants use self-selection (some with a provision that teams must have a prescribed mix of knowledge, skills, and abilities), some faculty use project selection (a form of self-selection), and some use criterion-based instructor-selection. Participants did agree that instructor-selection requires more of a faculty member's time than self-selection, yet they acknowledged the problems associated with self-selection, including those already identified in the literature.

2.2 Approaches taken by participants

The approaches described by the participants can be categorized as variations on self-selection and instructor-assigned with one hybrid approach, project selection, including aspects of both. No one mentioned the third main category, random assignments, confirming literature findings regarding the preponderance of disadvantages. Following are summaries of the approaches taken by participants, grouped by category.

Variations using self-selection include:

- Students self-select but teams must meet instructor-set criteria for mix of skills and roles.
- Students 'shop' for teammates using resumes, skills and qualifications; this approach often ties to winning a competition or having a superior product rather than to an interest on the learning of every student on a team.

Variations using instructor-assigned include:

- Use personality profiles (e.g. Meyers-Briggs).
- Use behavior-based profiles (e.g. engineering profile or Belbin's team roles).
- Cooperative-learning criteria: heterogeneity across all dimensions except schedule compatibility.

Variations using project selection include:

- Students select projects, not teams, though students wanting to work together may self-select the same projects.
- Instructors may have to re-assign students to match the team size to the project scope, having neither too many nor too few students assigned to a particular project.
- Instructors might require teams to swap members so that most teams have an appropriate mix of knowledge, skills, and abilities.

The wide variability among participants regarding team assignment suggests that while capstone faculty are exploring some of the available literature and drawing on professional practices, much work remains to better understand the educational value of these approaches, to provide faculty with sufficient information to make informed decisions about which approach to use, and to provide usable tools for enacting those decisions. Despite these gaps, one clear consensus did emerge from the discussion: participants clearly cared about defining and meeting the learning objectives associated with team assignments and about providing a high-quality student experience.

2.3 Factors affecting choice of approach

The concern that faculty expressed about the quality of the student experience seemed to be the most important factor affecting a faculty member's choice of approach to team formation. A close second in importance is the magnitude of the time commitment a particular approach demands and faculty clearly struggled when those two factors came into conflict.

In terms of student experience, faculty considered:

- Students' perceptions of the fairness of the process.
- Students' ability to determine their own strengths and weaknesses and to have opportunities to improve weak areas.
- Schedule compatibility (project work during scheduled class periods).
- The tension between performance and learning (described in more detail in the product vs. process section following).

In terms of time commitment, faculty experiences included:

- Consideration of the amount of 'extra' work imposed on instructor.

- Attempts to incorporate a new approach that are abandoned because of both time and 'hassle'.
- Experiments with several methods that are also abandoned because of both time and student responsiveness (students not completing necessary tasks).
- The simplicity of self-selection both as a process and in terms of bearing the responsibility for dysfunctional teams.
- Struggles with students who are 'left over' from the self-selection process; the process is easier as a whole, but students who don't fit into the self-selected groups must be placed somewhere.

We note two distinct aspects of faculty time commitment. The first is the time required to effectively assign students to teams. Use of dedicated teaming software packages can dramatically reduce the time required to assign students to teams and achieve distributions of team member attributes that meet an instructor's criteria [10]. The second is the amount of time an instructor spends with teams going through their 'storming' stage of development on their way to the 'norming' stage [30]. The collective experience of panelists and participants suggests that capstone faculty encounter a seriously dysfunctional team every year or two and spend a disproportionate amount of time trying to help that team succeed. Avoiding this particular time commitment was cited by one participant as the primary reason for self-selection: when a team has conflict, it's 'their problem, not mine.' Such an approach may not effectively support student learning, but it does indicate that for many faculty, effective management of small group dynamics is lacking in our education and experience.

Regardless of the method faculty chose for creating teams, participants and panelists noted that just putting students in groups does not teach them about teamwork. In any approach, the instructor needs to provide structure to guide learning, implying the need for well-articulated learning objectives and capstone project guidance to meet those objectives. Established methods include creating team codes of conduct or charters, students reflecting on their behavior, and peer evaluations. Moreover, we suggest that the teaming learning objectives gain complexity and depth as students' progress through a curriculum, consistent with a curriculum designed to prepare them for 21st-century engineering practice [31]. This over-arching theme requires a long-term commitment by faculty groups within a program or an institution.

2.4 Implications for faculty and researchers

The advantages and the disadvantages described by the participants agree with those described in the literature. At the same time, participants' experiences point to some critical guidelines for future faculty and to unanswered questions that merit further research.

Several key points emerged from this component of the discussion, including (as noted below) issues not directly related to team selection but that are often consequences of the selection process:

- Regardless of how one assigns or manages teams, faculty should 1) care about student learning about teams and on teams, and 2) take action informed by research results to improve their management of student teams.
- Students need to develop teamwork skills, including planning and virtual collaboration; the latter is particularly important in light of globalization, and students' ability to engage in internet-based social networking does not translate into an ability to engage in virtual professional collaboration, even with collaborators on their own campuses.
- Capstone courses need explicit conversation about what should be happening in teams, what might be missing from any given team, and how the gaps or problems can be addressed.
- In a capstone course, both students and faculty will be learners. One goal of a capstone project is to pose a problem to which the faculty member does not necessarily have all the answers, even about matters related to team functioning.

In addition to the broad question about what methods of team selection provide the best educational opportunities for various contexts, this portion of the panel discussion also raised some related questions:

- How do we negotiate teaching students that difference is not negative but instead can be productive to team dynamics?
- How do we balance methods for constructing effective teams (e.g. through personality tests) with students' right to privacy and with their interest on specific projects?
- How do students' best learn to be effective team members?
- What is the state of faculty member preparation for managing small group dynamics?

3. Product versus process

As with all good courses, the time required to master all of the material always exceeds the time available. Thus, the instructor is required to emphasize the most important aspects while reluctantly decreasing emphasis on other issues. Within a capstone course, two competing topics are successfully completing a large scale project and learning the various skills (group work, communication, design, etc.) required throughout industry. The tension between the time used within the capstone course to accomplish these tasks is labeled 'product versus process' and was discussed by the panel in the context of the following extremes.

Scenario 1: Consider yourself the manager of a team of students with an industrial customer, perhaps one that has provided funds for a project. Your goal is to successfully meet the needs of the client, with little or no concern about how it happens. You want the client to be happy, perhaps so they will fund projects in the future. The project must be delivered on time and on budget. To accomplish this 'real world' objective, student learning with respect to critical design processes—including teamwork –is sacrificed. If a team produces a good product, their approach and the learning experiences of each member is irrelevant. That is, 'product trumps process.'

Scenario 2: Your goal is not to produce a product, but rather to fully engage all students in the design process. The product itself has little or no meaningful value to any immediate stakeholder or client, and the product's success or failure has no consequences. Students are thus allowed to grapple with the process as long as needed to insure that they fully learn the complexities of collaborating in a design environment, but they never produce a functional product. In that case, 'process trumps product.'

These two extremes reflect the tension panelists and audience members sought to investigate. The tension between product and process has received much less systematic attention in the literature; existing literature typically focuses on either process-related goals or product-related goals. Compare, for example, capstone experiences that emphasize reflective journaling [32] and professional skills [33], both leaning more towards 'process', to capstone experiences that emphasize entering a competition [34] or simulating a manufacturing enterprise [35], both leaning more towards 'product.' Yet little if any systematic work is available exploring the relationship between the two in terms of either faculty responsibilities or student learning outcomes. Despite this gap in the literature, the tension raises an important question about the learning objectives of a capstone course and the importance of team processes versus product success, particularly in light of course time constraints.

While the literature does not explicitly or systematically explore the tension itself, evidence suggests that a majority of capstone instructors combine elements of both process and product in their courses. For example, Howe and Wilbarger [4] report that 'professional skills form the majority of the most frequently taught subjects' in capstone courses. Of the 444 programs responding to their survey, 87% include instruction in written communication, 83% in oral communication, 76% in engineering ethics, 72% in project planning and scheduling, 68% in decision making, and 66% in team building, all contributing to a successful design process. In the same report, a little over half the respondents report that outside sponsors provide support for some of their capstone projects and that 64% of sponsors possess at least part of the intellectual property associated with the capstone project, indicating a focus on the importance of the product. Moreover, Paretti and Pembridge found in 2010 that almost 60% of respondents considered process and product not only equally important, but interdependent; only 6% of respondents considered product alone most important, while 24% considered process alone most important (regardless of product success). The panel discussion reflected this sensibility, though as in the literature, it appears grounded in anecdote or 'gut feeling' rather than in a systematic study of student learning outcomes.

3.1 Panel perspectives: synthesis of the discussion

The panel at the 2010 Capstone Design Conference approached the problem by considering product and process, while not orthogonal, as certainly not mutually exclusive. The approaches taken by participants represented a range of responses, and while some faculty leaned more heavily toward process and others toward product, few if any consider either wholly dispensable. The participants agreed that a process that yielded no meaningful product—or at least a robust understanding of the sources of product failure —could not effectively teach students the design process. Conversely, a product that succeeded, when not backed by a systematic professional practice, also fails to prepare students for the workplace in which effective team decision-making and project management are critical and trial and error disastrously expensive. Consensus emerged among the participants that capstone courses need to balance the issues of product and process based on the curricular environment, the source of the project and the learning objectives of the course.

3.2 Approaches taken by participants

As noted above, faculty approaches were heavily influenced by context. In general, the discussion highlighted the following themes:

Environments that lead to an emphasis on product:

- Teamwork and design process through the curriculum: in curricula where students have multiple

prior courses that address team function and/or design process, capstone faculty are free to emphasize product quality.
- Industry sponsorship: when projects have industry sponsorship, product quality is a dominant factor, though as noted in the next section, faculty also manage industry expectations to align with student abilities.
- Departmental and individual learning objectives: in addition to the external influences of curricula and sponsors, departments and faculty members may prefer an emphasis on product for philosophical reasons.

Environments that lead to an emphasis on process:

- Lack of prior curricular scaffolding: when the capstone course is the first (or even second) major team design experience, capstone faculty seem more likely to articulate a significant need for process focus.
- Faculty/internal sponsorship: when projects emerge from faculty research projects or are developed by the students themselves, capstone instructors seem more willing and likely to emphasize process.
- Departmental and individual learning objectives: in addition to the external influences of curricula and sponsors, departments and faculty members may prefer an emphasis on process for philosophical reasons.

The 'approaches' taken by faculty (i.e. how they emphasized product or process) received little attention in the discussion; instead, the participants focused on the role of these factors in their decision, as detailed in the following section.

3.3 Factors affecting choice of approach

3.3.1 Curricular environment

As noted above, the curricular environment is central to faculty perceptions about the role of process versus product. Capstone design courses do not exist in a vacuum. Students entering the course have completed over 100 hours of course work, with dozens of courses within the degree. While engineering programs excel at providing students with the requisite content knowledge, as well as the ability to master any new technical content associated with a given design project, they vary widely in terms of the distribution of procedural and practice-oriented knowledge of the design process across the curriculum. Participants noted that students with significant design and/or teamwork experience throughout a curriculum can be expected to know and apply a robust, systematic design process, while students without such experience must learn during the capstone course. The higher the degree of curricular scaffolding with respect to design learning prior to the capstone course, the higher the level of product and process performance faculty expect.

Even though not all students will have progressed through the curriculum (e.g., transfers, optional degree plans), institutions with significant scaffolding allow the capstone experience to assume the existence of good process and increase the evaluation emphasis on the product, while still maintaining the emphasis on process as well. This scaffolding takes a variety of forms, including:

- Significant design experiences at multiple points across the curriculum (freshman, sophomore, junior, *and* senior years).
- Extracurricular design experiences associated with national competitions (e.g. Design-Build-Fly teams, Formula One teams, Human-Powered Vehicle teams, and those sponsored by engineering professional societies).
- Optional or required courses that cover topics such as teaming, entrepreneurship, and interdisciplinarity.
- A group of individual faculty committed to teaching teaming skills and behaviors in various courses throughout the program (not necessarily design experiences per se) and helping students build a skill set over an extended period.

Such structures are in place across the undergraduate curriculum, most notably at institutions such as Harvey Mudd College and Worcester Polytechnic Institute, where students undertake substantial team design projects throughout the curriculum, with increasing complexity and expectations. Typically in these cases, the final product includes not only the final artifact, judged by the degree to which it effectively satisfies the project requirements within the necessary constraints, but also the design documentation required to justify all decisions and reproduce the artifact. Both constructs can be evaluated within a rubric for the capstone course, and balanced by curricular, course, instructor and project goals.

On the other hand, institutions in which the capstone course is students' first experience with open-ended team projects (or their first experience since a cornerstone project in the first year) emphasize the process to provide students with the motivation to learn the critical components of design practice and engage in effective teamwork. In the absence of sufficient scaffolding, teams too easily fall back on late nights of random trial and error, coupled with heavy reliance on the 'smart' students. Surprisingly, teams that take this approach can succeed; as one panel member stated, 'With enough trips to Lowe's (a home-improvement products store), [good students] could make anything work.' Yet companies interested in profitability rarely accept such approaches; one struggles to imagine Boeing or Ford designing products via this method. Good engineering requires good design which should (among other goals) minimize the 'number of trips to Lowe's' and maximize the effective use of each team members' skills and strengths. Thus, to prepare students for design as it is practiced in engineering workplaces, capstone faculty emphasize process to help students develop as engineering designers and team members.

Participants also noted that in addition to the larger curricular structure, the time frame of the course itself also sways the product/process balance. Beginning a project without good process is very likely to cause delays and reduce quality, but postponing the start of the project until the students know the process reduces the time available to achieve that quality. Additionally, most students are also taking four or more additional courses of equal weight and thus cannot devote all their time to the capstone project (some schools, perhaps most notably Worchester Polytechnic Institute, have adopted structures that don't impose such time limitations, but they are the exception rather than the rule). Because there is a learning curve for both design and team processing, students' first attempts (i.e. in the capstone project) may demonstrate low quality in the final product but high quality in the learning. The course time constraints, in particular, reinforce the dependence on prior scaffolding: a weakly scaffolded curriculum decreases the emphasis on the capstone product in order to support student learning.

3.3.2 Project source

While curriculum structure defines what students can reasonably bring to the course, participants also noted that the source of the course projects often plays a significant role in determining product/process expectations. The panel identified four types of projects across a spectrum: industrial sponsored (most product-heavy); competitions; research sponsored, and course generated (least product-heavy). Each type corresponds to a different product/process balance overall, although there is some variance within the types as well.

Industry-sponsored projects can be the most demanding in terms of product, since a company can be paying money to generate the product. Students (and faculty) feel a responsibility to meet the needs of the customer because industrial sponsors provide real dollars for real products. However, the quality of students in a capstone course varies widely, and team formation comes back into play in the product/process balance. For example, faculty can produce a 'super team' capable of meeting the needs of one sponsor, but at the cost of significantly weaker teams for the other projects—a structure that in general is problematic. Overall, however, industry sponsorship brings a strong product focus, in large part because students see the need directly and develop a strong sense of ownership and obligation (especially with regular interactions with the sponsor). In such cases, session participants also report the need to counterbalance this effect and provide motivation for learning processes.

Competitions can result in poor products fairing badly, thus some students' competitive natures emphasize the importance of product, though this is less uniformly motivating. In addition, competitions allow emphasis on the process by virtue of the judging process. Combining grading based on the needed soft skills with performance in a competition enables the students to learn the process without fear of a failing project, while still providing motivation for success of the product. This combination is very beneficial in environments with weak scaffolding as well as motivational for programs with strong scaffolding. Candidate competitions range from local 'Best Design' competitions within a department or university to national and international events such as the ASME student design contest (http://www.asme.org/Events/Contests/DesignContest/Student_Design_Competition.cfm) or General Motor's Challenge X event (http://archives.media.gm.com/us/powertrain/en/news/events/challengex/2007/).

Research sponsored projects are usually within an academic unit, so process can be emphasized within the capstone course more easily. The science dimension shapes the definition of success for the project, and 'failure' can still equate to success in terms of discovery. However, the project may be sponsored by faculty with real dollars, and the best possible results are desired. At the same time, such projects occur within an academic environment where 'sponsors' are already aware of academic restrictions like semester boundaries, and work load limitations, and are simultaneously committed to student learning.

Finally, course generated projects have no real purpose other than providing the students with the capstone experience, and thus have the most freedom to emphasize the process rather than the product. With no external stakeholders, such options make it much easier for instructors to emphasize process, but undergraduates may approach these projects in much the same way they do other 'class' assignments and seek the best possible grade for the least effort. Thus this approach can lead to a possible lack of ownership by students. Faculty can balance process and product through the evaluation structure, and thus have the greatest freedom to choose the desired product/process balance. Moreover, in such cases, without external motivation through a sponsor, overemphasis on process combined with low student commitment to product success can result in no product at all.

3.3.3 Learning objectives and definitions of success

Finally, individual faculty and departmental preferences regarding learning objectives are critical in shaping the product/process balance and the definition of student success. While curricular context and sponsorship source play a role, faculty may also base definitions of success on how well the course mimics the work environment, or on how well the students are prepared for that environment. One approach discussed even focused on success based only on the experience the students have on the projects. Students can develop their own metrics for the projects, and their performance can be measured against those metrics. Grades are assigned, but success is determined by whether or not the student learned something that will help them in their career. One participant described using the Engineer Profile [36] as part of this approach. The profile defines ten roles for a project and ties them to behaviors. Students can self-report on the profile how they fit within these criteria, and where they expect the capstone course to help them improve. Thus success for an individual student may require the student to adopt an uncomfortable role. For example, team leader or modeling may not be a student's strength, but the capstone is the last chance for the student to receive that experience in an academic setting. This approach, however, does not always lead to the best product, leading to tension within a team if some individuals are trying to grow into a role, while others are expecting product success.

3.4 Implications for faculty and researchers

The discussion around the process and product in the capstone course highlighted several key implications for faculty:

- Decisions regarding the process/product balance should reflect not only individual faculty goals, but also departmental goals, curricular scaffolding, and sponsor expectations.
- At the same time, the desired product/process balance should in turn affect departmental decisions around curricular scaffolding and sponsor expectations.
- Although not a strong point of discussion, participants also noted that faculty workloads (including the number of teams under a faculty member's supervision) play a significant role in shaping the product/process balance.
- Prior learning experiences with team design projects better prepare students for a product-oriented capstone experience.
- Industry-sponsored projects lean most naturally toward a product emphasis.
- Successful capstone courses balance the requirements of both product and process based on context. The key is to understand the environment, to develop appropriate projects and to define learning objectives enabling successful outcomes for the students, the faculty and the project partners.

At the same time, the panel discussion also revealed a number of key questions for future research in the product vs. process tension, including:

- What degree of team and design knowledge do students need before product should become a dominant criteria?
- How can teams be mentored to best help students learn effective, transferable processes.
- How does an emphasis on process affect students' ability to engage in successful design?
- How does an emphasis on product affect students' ability to develop as effective team members?

4. Technical practice versus professional practice

The final question the panel considered was, 'When mentoring student teams, should faculty be concerned only with students' ability to deploy technical knowledge effectively to solve the problem, or should they also address professional issues surrounding team dynamics, including gender, race and ethnicity, and communication and interpersonal skills?'

The importance of these professional issues in undergraduate development is clear from the literature. For example, Tonso's ethnographic study of design teams identified significant subtle cultural biases that negatively impacted some women's experiences [37–38]. Similarly, Foor's study of race and class highlights the ways in which these factors can influence students' ability to engage in and learn from team projects [1], though work in these areas remains limited. Yet issues of diversity in teams still seem difficult to discuss for engineering faculty, and even in the panel session there was some resistance to discussing or directly confronting these issues. In contrast, faculty are more than willing to discuss issues surrounding professional communication, though *who* is responsible for that instruction remains unsettled. More work has been done, including more curriculum development, around the issue of communication in design courses at both the first-year and capstone levels [40–43]. In addition, as McKenzie et al. note, communication is the most dominant skill assessed by capstone faculty and written and oral reports are the most important means of assessing performance in the capstone course [5]. The surveys of capstone faculty, as noted above, also consistently place communication as a critical learning objective and topic taught in the course [4, 6].

4.1 Panel perspectives: synthesis of the discussion

Rather than addressing the relationship between technical and professional skills, the participant discussion focused first on the appropriateness of addressing diversity issues in the capstone course, and then turned to the need for strong communication skills. The issues as posed by the moderator elicited some strong negative responses to the phrasing related to gender, race, and ethnicity. Concerns were raised regarding possible stereotyping on the basis of race or gender, and the question was rephrased to address the needs of our student populations. The discussion addressed the effects of low levels of both faculty and student diversity at some schools on student experience; studies of the impact of factors such as race and gender on team behavior bear out these concerns [37–38]. Despite some discomfort and resistance to addressing these issues within capstone teams, other participants believed that the broad question has validity. As one member of the session noted, 'If you think that communication, information literacy, and social/ cultural impact are not part of design, you probably shouldn't be teaching design. They're fundamental to the process. Design isn't just doing the math. If you're not attending to these issues, you are probably not engaged in design in its fullest sense.'

Nevertheless, discussions about the dynamics of diverse teams were limited, perhaps due to participant discomfort, and the discussion focused on the interpersonal skills associated with communication. Much of this discussion centered on the current writing skills of our students and the need for improvement, though some participants also addressed oral reports as well as less formal modes of writing and speaking. There seemed to be agreement that attention to technical communication is appropriate and is needed in the design curriculum, but approaches for incorporating that instruction varied significantly across individuals and institutions.

4.2 Approaches

After a brief discussion that highlighted the role of diversity in team dynamics, the session focused on approaches to technical communication. Technical writing in particular appears to be difficult for design engineering faculty to address appropriately. Additionally, the writing process appears to be difficult for some students to grasp. Students must understand that, '. . . the first draft is not the final draft.' The discussion highlighted, in particular, the need to provide capstone faculty with effective tools and approaches for teaching communication. Participants highlighted a range of possible approaches:

- Writing or communication experts team-teach or provide lectures within the capstone course. In many cases, this approach also includes guidelines or templates for developing design reports expected by an experienced professional engineering manager.
- Technical writing and speaking assignments are integrated across the curriculum. As one participant explained it, 'Writing, talks, and extensive lab reports background where technical writing is emphasized [in multiple courses], so by the time they get to Capstone good writing is expected. Talks and papers will fail if high expectations are not met.' Another noted, 'If they've had experiences throughout the curriculum, if they've learned to be efficient, they can respond to the instructor explaining how the instructor will use the information (usability of writing).'
- Skills are not separated out for explicit teaching, but the integration of projects across the curriculum embeds effective communication within design project experiences. One participant explained, ' . . . there are no classes in skill A, . . . skill B . . . instead we give a project and say 'Here's a project. Do it'. Every project is individual. Every group skill in the context of the project experience. Huge faculty commitment to learn through the project. This approach is consistent with the Sheppard report 'Educating Engineers' recommendations [31]. Learning through the project rather than learning something first . . . then applying it in a project.'
- Faculty model effective behavior, particularly with respect to oral presentations. Technical presentations and design reviews are expected in most capstone programs, and participants agreed that oral communication may be easier for the students to develop and easier for the faculty to assess. As one participant noted, 'We demonstrate through our actions what is important. Every time we give a lecture, we are demonstrating our standard for oral communication. If we want students to be good oral communicators, we should be good oral communicators ourselves. If we want them to have good skills in team

dynamics, we should demonstrate those skills ourselves.'

While the approaches varied based on institutional priorities and resources, the desire for strong written and oral communication skills clearly reflected a strong need among many teams, and participants acknowledged the complexity of teaching and learning in this area. One panelist explained the challenge as follows: 'Learning to communicate is a complicated process. Most of us learn to communicate by doing it in context and by getting responses from people who actually need the information we have. Good writing is writing that is useable.' As the approaches listed above suggest, however, both the balance between technical skills and communication skills and the responsibility for teaching communication remains unresolved. At the same time, few clear contextual factors emerged as drivers that shaped faculty approaches.

4.3 Implications for faculty and researchers

As suggested above, the intensity of the discussion indicated that most participants clearly see a need for strong communication skills, but many participants hoped to rely on outside experts (e.g. technical communication faculty) and struggled to find the time necessary to provide instruction and feedback within the course. Thus in terms of the balance between technical and professional skills, the desire for professional competencies struggles against a lack of both time and teaching expertise. Overall, however, the session discussion did highlight the need for engineering faculty to be more engaged with the student teams in the communication process. Some of the most productive responses reflected an integration of skills across the curriculum and partnerships between technical faculty and communication faculty marked by shared goals and ongoing dialogue.

At the same time, resistance to addressing team dynamics with respect to gender, race, ethnicity, class, sexual orientation, and related identity markers suggest that engineering faculty need to develop a stronger understanding of the ways in which identity factors into team performance, and a stronger set of tools and approaches for addressing these factors in the context of design projects. These factors clearly effect students lived experiences in teams [37–39], yet most faculty lack effective means of addressing these questions. In this case, the 'balance' clearly leaned away from addressing these issues within the course, but that decision may not match either the learning outcomes that students need or the actual dynamics of capstone projects.

In seeking to address this imbalance, the moderator proposed that perhaps the attitudes and behaviors of our students regarding these concerns are largely a reflection of our own departmental culture and behaviors. If we do not demonstrate a commitment to communications excellence, awareness of social impact of design, awareness of race and gender and the effects it can have on teams, then we should not expect our students to meet these objectives. Perhaps we should reflect on our departmental or institutional behaviors and attitudes and work on improvements in these areas.

Finally, the discussion surrounding professional skills in capstone teams highlighted several additional research questions:

- Although some research already exists, many questions remain about the impact of diversity issues on both team performance and individual student learning outcomes.
- What approaches are best suited to helping faculty effectively engage issues of diversity in team mentoring? How are those affected by the overall demographics of the student population?
- What strategies can help faculty effectively and practically integrate communication into capstone courses? What approaches help build partnerships with communication faculty? What helps faculty develop the ability to teach communication?
- How does the balance between technical and professional skills affect student learning? What learning outcomes are most appropriate for the course.

In addition, despite the work done by researchers specializing in communications, social impact of engineering, and race and gender studies, key questions concern the intersection of those bodies of work and student experiences in capstone courses. For any of these broad topics, we have two key questions:

- What characterizes an exemplar?
- What strategies are effective in changing the culture?

5. Conclusions and future work

The panel explored three critical tensions faculty face when managing and mentoring teams: team creation, team process versus team performance, and technical versus professional team outcomes. In each case, faculty shared much common ground around the nature of the tension, but often had very different perspectives on the appropriate resolution. Those differences arose from both professional contexts (e.g. curricular structure, department expectations) and personal contexts (e.g. beliefs, prior experiences, level of comfort and understanding). In each case, faculty were united by their understanding of the importance of learning objectives in resolving the tension, and the tenor of the discussion throughout clearly reflected faculty members' commitment to student development. At the same time, university and departmental cultures as well as personal experiences played a key role in shaping responses, as well as in preparing students for the capstone experience and modeling the expected outcomes.

Broadly, the discussion demonstrated the need for faculty to approach managing and mentoring capstone teams by considering issues such as:

- Student motivation and its effects on the team environment.
- Explicit and implicit expectations for team performance by both faculty and team members.
- The role of virtual networking experiences in preparing students for the global workplace.
- Curricular support for design and team processes
- Student experiences prior to capstone.
- Availability of projects and curricular implications of sponsorship structures.
- The importance of and support for professional skills, particularly for communication excellence, but also interpersonal dynamics.
- The role of behaviors demonstrated by the department and the engineering culture in shaping team experiences.

All of these factors must be integrated when designing the team-related learning objectives (and subsequent course experiences) of a capstone project in order to enable students to succeed not only within the classroom, but in their initial work experiences. The capstone course serves as the last opportunity for engineering departments to prepare their students for life after college. It is imperative these courses demand the most from the students, and from the faculty involved.

At the same time, the tensions and difficulties faculty experience in addressing these issues, the diversity of opinions and experiences among the participants, and the lack of a coherent body of supporting scholarship point to the need for more robust research to increase our understanding of student learning and to provide faculty with practical approaches for addressing these issues in their courses. In addition to the specific questions raised within each section and summarized in Table 1, promising research directions emerging out of this panel include:

- The process by which students learn to become effective team members.
- The role of student motivation in team performance and learning.
- The ways in which product and process emphases affect not only team performance, but student learning.
- The role of professional and interpersonal skills in team learning.
- The ways in which identity affects both team performance and student learning in team settings.

As the capstone teaching community continues to engage in meaningful discussion around core teaching issues, the primary outcome for our field at this point is the identification of shared questions and concerns, as exemplified by the work of this panel. These shared questions and concerns can lead us to sustained, collaborative scholarly inquiry into the teaching practices that best support student learning—a goal that is clearly at the heart of capstone instructors. Faculty engaged in mentoring capstone teams demonstrate a strong commitment to fostering students' professional skills and helping students develop as team members, but much work remains to fully support them in this effort.

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