

Enhancing Team-Based Senior Capstone Projects: Opportunities and Challenges

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Abstract

In response to a changing workforce, universities have added a wide variety of diverse learning outcomes to the undergraduate curricula¹. In engineering technology, senior capstone courses provide a primary mechanism by which students integrate and apply technical knowledge and skills acquired in previous coursework. However, capstone courses also require students to focus on a variety of professional skills, including teamwork, unstructured task completion, and project management². Because students are often new at these skills, they may find it difficult to resolve issues as they arise.

Capstone courses also pose challenges to faculty. Finding a consistent stream of projects that are at the appropriate level for senior level students can be difficult for faculty given the limited time frame of most courses. A fair and consistent method to evaluate student work on an individual and group level is also a challenge for instructors.

This paper will outline the challenges and best practices learned in the development and implementation of a senior-level capstone course in engineering technology, based on qualitative data gathered over several years. Specifically, strategies for sourcing student projects, student team formation and management, and options for ensuring accountability among student teams will also be discussed. Ideas on fair and consistent assessment methods for group and individual work will also be emphasized.

Senior Capstone Course Design

The senior capstone course represents a critical role in many engineering and engineering technology programs, even given the large variation of course structure and format across many diverse educational institutions³. According to Pembridge and Paretti³, a large number of capstone courses in the field of engineering focus on a project spanning one or two semesters and involve teams of 4 to 6 students. The emphasis of capstone courses generally give students the

opportunity to apply technical tools, techniques and knowledge learned in the classroom to an open-ended, realistic, and creative problem-solving experience⁴.

In addition to technical skills, capstone courses also require students to focus on a variety of professional behaviors, including teamwork, conflict management, customer service, and project management. Additionally, professional skills such as an understanding of the historical context, creativity, and critical thinking are also considered important components of a capstone course⁴. Gorman⁵ (2010) also notes the difficulty many students have in presenting a solution clearly and concisely. Although students generally learn a number of sophisticated methods for problem solving and data analysis in their coursework, they often fail to recognize that the best solutions are simple and may not always involve complex analysis. Furthermore, students who take the time to carefully formulate the goals of the project, recognize the limitations of the context, and who question assumptions and solutions of the existing system often provide higher quality solutions⁵.

The capstone experience discussed in this paper is part of an engineering technology program in an agricultural and biosystems engineering department. The department includes four majors: agricultural engineering, biological systems engineering, agricultural systems technology, and industrial technology. The author leads one of two sections of senior capstone courses in engineering technology (which includes the majors of agricultural systems technology and industrial technology) offered by the department. Students from the two majors in engineering technology take the required two-course sequence in their final year of their degree program. Teams of three to four students are assigned a project in the middle of the first semester and complete the project by the end of the second semester.

The first course in the sequence is one semester credit and the second course in the sequence is five semester credits. Historically, the number of students enrolled was approximately 20 students per semester. The author has taught the course for three years, but in that time the enrollment has increased dramatically, as shown in Figure 1. Increased enrollments have influenced the way the senior capstone course is taught, but the overriding goal is to keep the hands-on, problem-solving nature of the course, even when the number of students and projects is larger than in the past.

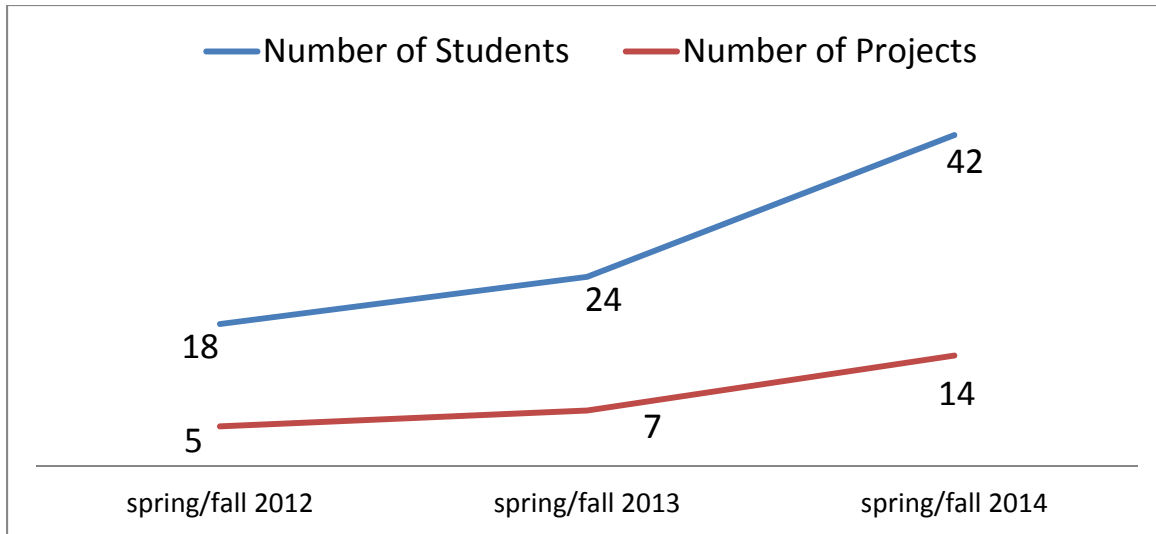


Figure 1. Students enrolled in senior capstone course

Industry Projects

The history of the engineering technology capstone in the author's department is to use industry-based projects in the senior capstone course. Part of the reasoning is based on the assessment of Shuman et al. ⁶, who encourage the use of out-of-classroom experiences, such as capstone courses, to “effectively integrate the learning of multiple outcomes into one comprehensive, educational experience” ⁶. Furthermore, they recommend a curriculum model where technical coursework is thoughtfully incorporated with humanities and social sciences in the first three years to support a senior year capstone experience that has the potential to benefit the student as he or she enters the workplace.

One way to facilitate this integration is by the use of industry-sponsored capstone projects. Industry projects provide the mechanism for external and expert opinion needed for appropriate validation of learning, as required by many accreditation bodies. Kauffman and Dixon¹ describe projects that examined the capstone course as it related to outcomes in teamwork, communication, and lifelong learning. Kauffman and Dixon¹ also studied the solicitation, identification and review of potential capstone projects in their 2011 work. They recommend a process where faculty are very involved with the choice of projects as well as the evaluation of the scope and the identification of a key contact person at the company where the project will take place.

Industry projects are valuable to students but are also challenging from many perspectives. Magleby et al.⁷ and Friesen and Taylor⁴ examined the decision to use industry-sponsored projects and outline both positives and negatives to such projects, shown in Table 1.

Table 1. Positive and negative aspects of industry-sponsored capstone projects

Advantages	Disadvantages
Enhances student motivation	Consequences of failure have greater impact
Creates realistic problems and environments	Recruitment of projects may be challenging
Faculty can observe student in non-academic environment	Intellectual property and liability may be of concern
Means of financial support and outreach with industry	Administrative procedures and protocols must be developed and managed carefully
May assist with career placement of students	Faculty may be uncomfortable outside of expertise

Magleby et al.⁷ further recommend that instructors carefully consider the scope of the project and the feasibility of its fit with University policies, timelines, and resources. Although they recommend that the project meet a company need, it should not be an acute and urgent necessity for the company. Furthermore, Magleby et al.⁷ suggest that a liaison person between the company and university plays a critical role in success. The liaison must be someone from the company who has a vested interest in the project, can provide adequate supervision to the students, and who is not intimidated by University policies and procedures

Although industry-sponsored projects provide an authentic experience for students, the “real” nature of such projects can be risky because of the high stakes challenges and technical issues that must be resolved by student teams. These teams are generally novices in the application of problem-solving techniques and project management and may need structure and guidance not necessary for a team of seasoned professionals. Even so, the experience of an open-ended and creative problem solving exercise is valuable to students⁴.

Students are not the only beneficiaries of capstone courses. Industrial clients also benefit from their involvement with capstone courses. According to Friesen and Taylor⁴ industry may serve in one of several roles within the capstone course. They may serve as the project provider and client

to a student or student team, they may provide sponsorship to student teams, they may serve as a technical resource or consultant, serve as the project liaison, or provide assessment of the project, either in a formal sense (by grading the final paper or project) or in an informal sense (by providing prizes in capstone competitions or by serving on an evaluation “jury” to judge capstone projects). In return, students provide industry with cost-effective way to access fresh ideas and updated expertise.

Industry-sponsored projects are a long-standing tradition at the author’s institution. To address the issues identified by previous engineering educators (as outlined by Magleby et al.⁷ and in Table 1) concerning the use of industry-sponsored capstone projects, several actions have been taken at the program, department, and college level. The first of these is a project form. The project form describes the engineering technology capstone program, gives examples of past projects, and provides space for the industry representative to outline the purpose and goals of the proposed project.

The form is created by the University to guide the thought process of industrial sponsors on project development. This form is circulated among departmental supporters and alumni. In addition, when contact is made through the University’s service unit for short-term projects, this form is sent to prospective clients, who in turn complete the form with a potential project idea or ideas. Project concepts are submitted to the faculty member, who will then vet the projects and share projects that are selected with the students or selection.

The use of the forms provides several benefits for faculty and addresses several challenges identified by the National Academy of Engineering in 2012. First, all projects are vetted by the instructor or instructors before being accepted as a potential capstone project. This allows for projects to be appropriately scaled for the time period allowed, which is one area of challenge identified by the National Academy of Engineering in their 2012 best practices report⁸.

A second advantage of the project forms is that it requires prospective clients to think seriously about the scope of the project before agreeing to participate in the capstone course. A key component of recruiting high-quality industry projects is persistence⁸. Early planning and tempering expectations are also suggestions from the National Academy of Engineering⁸ report. Engaging industry partners through the departmental advisory board and by involving them in

early planning are also practices recommended by the National Academy of Engineering⁸ that were implemented with the use of project forms.

A third advantage of the project forms is that they identify key contact person at each company where projects take place. As suggested by Magleby et al.⁷, the forms allow the instructors to review the project to ensure it is a good fit with University policies, timelines, and resources. Additionally, concerns with intellectual property and liability can be addressed up-front rather than in the middle of the project.

Finally, the project forms facilitate a strong and structured administration and communication plan between the industrial client and the university. Friesen and Taylor⁴ identify this as a key component for the success of university and industry collaborations. With appropriate definition, management, and monitoring, industry-based capstone projects have great benefits to student learning⁷. These recommendations reflect earlier conclusions by Todd, Sorensen, and Magleby⁹ on the design of capstone projects for industrial clients.

Team and project selection and management

Although industry projects are valuable to students, they have challenges that can make the management of projects difficult. One of the most common difficulties is that capstone project work is often completed in teams^{10, 2, 11}. The team approach is generally considered essential to capstone projects, in part because of the social negotiation and integration of multiple viewpoints necessary in complex projects¹⁰.

Three methods of team assignment are self-selection, random assignment, and teacher assignment. Teams that are self-selected are more likely to be overly homogeneous, have an inadequate skill set, and may lead to clique-like behavior that can negatively impact team cohesion and performance². However, self-selection of a team can give students more control and responsibility for their learning experience. Higher levels of accountability and cooperativeness are also noted with self-selected teams¹¹.

Random assignment has several disadvantages but no clear advantages. Although it seems fair, random selection of team members does not account for skills, diversity of students, or the variety of student abilities¹¹. Randomly selected teams do not generally lead to teams with

desirable combinations of skill sets nor do they promote teams that want to work together. The chance that the skills and abilities align appropriately is just that – a chance. Therefore, a random selection process is not recommended for teams which will work together on a long term (one to two semesters in length) capstone project.

A third approach to team formation is instructor-assigned teams. Although Bacon et al.¹¹ report that this approach is used rarely in team formation, the method has several benefits. Instructor-selected teams can be chosen to optimize the best distribution of skills and abilities among teammates. As discussed by Paretti et al.², (2011), instructors may use several factors to group students, including personality profiles, behavior-based profiles, and cooperative learning criteria such as the Team-Based Learning approach promoted by Michaelsen, Knight, and Fink¹². The Michaelsen et al.¹² method focuses on factors such as team cohesiveness and accountability. Individual skills are viewed as “assets” and a lack of skills is termed a “liability”. When student assets and liabilities are dispersed among the teams, groups have a tendency to be more effective¹².

Students generally do not have the necessary experience to form their own groups using these criteria. For this reason, the best scenario is to have the instructor assign the teams. The process works especially well in capstone groups, which tend to work together for a long period of time. Instructors may also employ a variety of variations in this method, including allowing students to choose projects rather than teams or requiring students to swap group members as needed to have an appropriate mix of knowledge skills, and abilities².

Several of these concepts were combined to form a team selection methodology for the capstone teams taught by the author. Early in the semester, students must complete a learning styles survey. This activity is more for the students’ benefit than for the instructor - students often do not understand how they best learn and this activity gives them a chance to think about and reflect upon on their preferred learning style. Students also complete a detailed form where they identify which courses they have taken, what project management activities they enjoy, and how they handle deadlines and large projects. In class, work styles and project management concepts are discussed and students are prepped for the project assignment process.

As part of the project and team assignment process, students are required to submit a written “bid” that outlines the top three projects (selected and presented to the class at an earlier date by the instructor) they are most interested in completing for their senior capstone project.

Additionally, students are required to explain their background and working style and how these skills and abilities would support their work on a specific project. Students may select more than three projects if they wish. They may also explain which projects they would rather not work on.

As part of the written bid assignment, students were allowed to indicate fellow classmates they would like to have as teammates. Students may also identify classmates they would prefer not to work with. Although it was not always possible to honor every request to work with a specific classmate, requests to not work with a certain classmate were always honored. As shown in Table 2, most of the 42 students did not indicate a specific person to work with or not work with. Their preferences and ultimate assignments were driven almost entirely by their project requests.

Table 2. Student requests for team selections

Action	Met	Not met
Specific teammate request (n=15)	9	6
Teammate Non-request (requesting to <u>not</u> work with someone) (n=12)	12	0
Assigned to one of top 3 project choices (n=42)	41	1

N=42

The entire process for project and team selections lasted approximately three weeks. Although the process of assigning teams and projects closely resembled putting a gigantic jigsaw puzzle together, the final outcome has been very positively received by students. While students have some say in whom they work with and which capstone project they work, the instructor makes the final selection. The process also is inclusive for students who may not have friends or acquaintances in the course. All students receive a project that they already feel some ownership and connection with. The process worked very well and will likely be repeated for the next round of project and team selections in 2015.

Fair and Consistent Grading

One of the biggest instructional challenges of team-based capstone projects is the development of a fair and consistent assessment system. Dutson et al.¹³ suggest that evaluation of student capstone projects is inherently subjective and Brackin et al.¹⁴ point out that failure of the end product does not indicate that no learning has occurred. Therefore, project success is not always the best indicator of the quality of work by either individuals or by teams.

Given these challenges, grading of capstone teams must involve accountability, for both individuals and the group¹². Bacon et al.¹¹ suggest a heavier weighting of team activities in the calculation of the final course grade. The assumption is that portions of the course that have a higher impact on the grade will result in a higher level of work.

One way to integrate more team-based evaluation into a course is to provide multiple opportunities for peer evaluation¹¹. The basis for peer evaluation is to counteract the tendency toward “social loafing” – a phenomenon that occurs when individuals lower their effort when working in a team, assuming that other members will pick up their work tasks¹¹. Michaelsen et al.¹² and others suggest that a single peer evaluation is not as effective as multiple evaluations that occur as part of team activities throughout the course¹⁵. To ensure full participation of all team members, a clear vision for what is expected of all members of the team and this leads back to a structured management plan for capstone teams¹⁴. Peer evaluation provides team members the means to indirectly address low performance by other team members. In addition, the peer evaluation scores given by teammates constitute approximately 25% of the final grade.

A second way to engage students in the process and to enhance accountability is by using low-stakes assignments¹⁶. In this course, students are required to individually submit a “memo” to their instructor after each instructor and team meeting. By providing a synopsis of the content covered in the meeting, they accomplish two tasks: 1) forced record-keeping on project details and 2) providing an indication of accountability for both attending and remaining engaged during the instructor/student meeting. The assignment also gives students the opportunity to summarize what they perceive as the important components of the meeting – completing the learning competencies of evaluation and synopsis – both of which are at the highest levels of Bloom’s Taxonomy¹⁷. The individual meeting synopses comprise approximately 25% of the final grade.

Together with the peer evaluation scores, nearly 50% of the grade is based on individual contributions and the quality of team contributions. A third component of team projects is the management of conflict¹⁴. Remembering that students generally do not have the skills to remediate major conflict within their team, effective mentoring from the instructor is important. However, providing a clear path for expectations and the structure of the course also assists students. Having policies which outline consequences of actions (or non-actions) are also helpful to resolving conflict before it escalates¹⁵.

Implications for Faculty

Ultimately, teaching a capstone course to technology students is a challenging endeavor with many considerations. Preventing a failed project must include careful attention to multiple items. These include¹⁴:

- Scope of the project - determining the feasibility and well-defined goals
- Scheduling of resources and time - accurate estimate of time and resources needed for success
- Effective management of uncertainty - related to the open-ended design of most capstone projects and the lack of student experience with such projects
- Strategy for resolving project conflict – disagreements on project definition, project approach, work style, communication methods, and other important decisions

Even with the suggestions above, the process of selecting, managing, and evaluating a successful capstone project remains an art rather than a science¹⁴. Several items must be considered in the development of authentic but feasible senior capstone projects. First, consider the benefits and costs of using industry-sponsored projects. Second, think in advance about how to construct student teams and about the methods you could use to assess your students and resolve team conflict, both individually and as a group.

Finally, remember that although poor experiences provide valuable learning for students, a successful project energizes all participants – the students, faculty, and the industrial client. In addition to an excellent learning experience, a positive project gives the students confidence in their skills and abilities and may provide a beneficial long-term relationship to the industrial sponsor and the institution, leading to further opportunities for capstone improvement and

evaluation. Although leading a capstone course can be challenging, it can also be very rewarding for students, faculty, and industrial clients and remains one of the best ways to evaluate how well students have learned to apply the technical content they have been taught.

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