Role of Senior Capstone Courses *in* 21st Century *Technology*

Undergraduate Programs

DEVELOPING THE 21ST CENTURY WORKFORCE

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Introduction/ Summary

Preparing undergraduate students to enter the workforce is a continuing challenge for institutions of higher education. In response to a changing workforce, universities have added a wide variety of diverse learning outcomes to the undergraduate curricula (Kauffmann & Dixon, 2011). The application of technology classroom content to workplace settings, critical judgment and evaluation, teamwork, and effective oral and written communication are professional skills that graduating students must master by the time they enter the workforce (Paretti, Layton, Laguette, & Speegle, 2011). In the context of higher education, capstone courses provide a primary mechanism by which students use these skills as they engage in open-ended, realistic, and creative problem-solving experiences (Friesen & Taylor, 2007).

In addition, capstone projects are increasingly utilized in undergraduate engineering programs as a result of accreditation requirements and the changing attitude among faculty that students need the hands-on practical experiences that a capstone project can provide (Paretti et al., 2011). The accreditation goals play a large role in the development of capstone courses; therefore, the creation of learning objectives and activities for such courses is not insignificant. In many cases, senior capstone courses include learning outcomes that focus equally on the development of technical skills along with professional skills such as public speaking, management, and understanding the larger implications of one's work (Shuman, Besterfield-Sacre, & McGourty, 2005). Reconciling the technical and non-technical learning outcomes can be difficult, particularly when capstone projects involve an industry sponsor.

To provide a summary of current thoughts and practices on undergraduate capstone courses, this white paper will contain three major portions. Positive student outcomes and potential institutional uses of capstone courses will be discussed in the first portion of the paper. The second part of the paper will discuss the challenges of implementing a high-quality capstone course in a technology-based curriculum program. Specifically, considerations for sourcing student projects, student team formation and management, and fair and consistent assessment of students will be discussed. Implications for technology faculty who wish to embark on the development of a senior-level capstone course will conclude the paper.

Capstone courses provide many benefits to

undergraduate students in the field of technology, even considering the large variation within course structure and format. According to Pembridge and Paretti (2010), most capstone courses in the field of engineering involve teams of 4 to 6 students who work on one project spanning either one or two semesters. The courses also focus on giving students the opportunity to learn how to use technical tools, techniques and knowledge in an integrated and applied setting (Gorman, 2010). Traditionally, students learn and practice skills such as the use of Pareto analysis, benchmarking, statistical process control, and root cause analysis (Gorman, 2010).

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 deemed important components of a capstone course (Friesen & Taylor, 2007). Gorman (2010) also notes the difficulty many students have in presenting a solution clearly and concisely. Although students are taught a number of sophisticated methods for problem solving and data analysis, they often fail to recognize that the best solutions in business are simple and may not always involve complex analysis. Furthermore, students who take the time to carefully formulate the goals of the project and who question assumptions and solutions of the existing system often provide higher quality solutions (Gorman, 2010).

In addition to the benefits capstone courses provide to students, the courses also play a critical role in the accreditation of engineering and engineering technology programs (Shuman et al., 2005). Although accrediting bodies can specify program outcomes necessary for engineering and engineering technology programs, the methodology of meeting these criteria vary across courses, disciplines, and institutions (Kauffmann & Dixon, 2011; Dutson et al., 1997). Capstone courses provide one mechanism of integrating technical and professional learning outcomes required by many accrediting bodies. For example, the ATMAE accreditation standards specify that baccalaureate programs must validate their outcomes and student competencies through a "combination of external experts, an industrial advisory committee(s), and follow-up studies of program graduates" (ATMAE, 2013).

Student & Institutional Benefits

Shuman et al. (2005) suggest that the integration of technical and non-technical skills is not only possible, but advantageous to degree programs. They 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" (Shuman et al., 2005). 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 both the student and meet the needs of accreditation.

One way to facilitate this integration is by the use of industry-based capstone projects. Industry-sponsored projects may also provide the mechanism for external and expert opinion needed for appropriate validation, as required by many accreditation bodies. Kauffmann and Dixon (2011) describe projects that examined the capstone course as it related to outcomes in teamwork, communication, and lifelong learning. Kauffman and Dixon 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. They also believed that the selection of capstone projects should be undertaken with outcomes assessment and curriculum evaluation needs in mind.

Challenges of Capstone Project

Even without program assessment requirements, industry sponsored projects can be challenging in several ways. Magleby et al. (2001) and Friesen and Taylor (2007) 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 (2001) 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. (2001) 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-based 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 students (Friesen & Taylor, 2007).

Students are not the only beneficiaries of capstone courses. Industrial clients also benefit from their involvement with capstone courses. According to Friesen and Taylor (2007) 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.

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Although industry projects can provide great benefits to students, they have challenges that can make the management of projects tricky. Friesen and Taylor (2007) suggest that a strong and structured administration and communication plan between industry and university is a key component for the success of university/industry collaborations. With appropriate definition, management, and monitoring, industry-based capstone projects have great benefits to student learning (Magleby et al., 2001). These recommendations reflect earlier conclusions by Todd, Sorensen, and Magleby (1993) on the design of capstone projects for industrial clients.

A second challenge of capstone projects is that generally project work is completed in teams. Dym et al. (2005) assert that the nature of most capstone projects requires a team approach, in part because of the social negotiation and reconciliation of multiple points of view necessary in complex projects. Paretti et al. (2011) and Bacon, Stewart and Silver (1999) discuss three methods of team assignment: self-selection, random assignment, and teacher assignment.

Self-selection teams 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 performance (Paretti et al., 2011). 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 teams (Bacon et al., 1999).

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 abilities (Bacon et al., 1999). 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., (1999) 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., (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 Fink (2004). The Michaelsen et al. (2004) 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 effective (Michaelsen et al., 2004). Because students generally do not have the necessary experience to form their own groups using these criteria, 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 abilitiess (Paretti et al., 2011).

A third challenge of capstone projects, especially with group work, is the development of a fair and consistent assessment system. Dutson et al. (1997) suggest that evaluation of student capstone projects is inherently subjective and Brackin et al. (2011) point out that failure of the end product does not indicate that no learning has occurred. Given these challenges, grading of capstone teams must involve accountability, for both individuals and the group (Michaelsen et al., 2004). Bacon et al. (1999) 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.

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A second way to integrate more team-based evaluation into a course is to provide multiple opportunities for peer evaluation (Bacon et al., 1999). 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 tasks (Bacon et al., 1999). Michaelsen et al. (2004) and others suggest that a single peer evaluation is not as effective as multiple evaluations that occur as part of team activities throughout the course (Freeman & Dyrenfurth, 2004). 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 teams   (Brackin et al., 2011). When faculty emphasize the importance of each person's contribution, the challenges of team assessment can be minimized.

Faculty Implications

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 include (Brackin et al., 2011):

- 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 science (Brackin et al., 2011). For faculty interested in taking on the instruction of a senior capstone course, it is important to consider many of the items discussed in this white paper.

First, determine the role that your accreditation process may have on your educational outcomes for the capstone course and plan accordingly. Second, consider the benefits and costs of using industry-sponsored projects. Third, think in advance about how to construct student teams (if you opt to use teams) and about the methods you could use to assess your students, individually and as a group.

Finally, understand 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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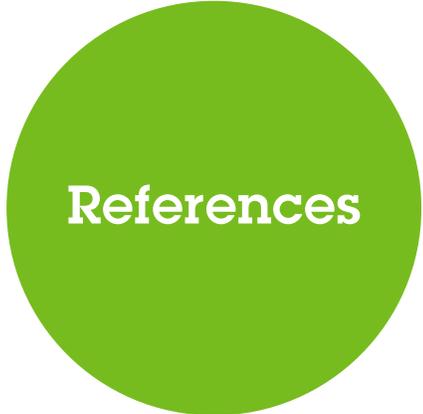
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