Managing Engineering Capstone Design Teams: A Review of Critical Issues and Success Factors

Abstract ID: I1107

Zikai Zhou
Department of Engineering Management & Systems Engineering, Old Dominion University
Norfolk, VA 23529

Pilar Pazos, Ph.D.
Department of Engineering Management & Systems Engineering, Old Dominion University
Norfolk, VA 23529

Abstract

New product development teams are at the core of the engineering discipline and have been recognized as essential contributors to corporate effectiveness. Educational institutions have invested great effort into developing approaches to better prepare engineering students to become active contributors to engineering design in their future careers. In this paper, we conducted a systematic review of prior research on the factors influencing the effectiveness of capstone design courses in engineering from three major engineering education journals. This paper synthesizes the findings and identifies the issues faced when designing and managing a capstone design course and the factors that drive the effectiveness of capstone design teams in the engineering education environment. We conclude by providing some recommendations and considerations.

Keywords
Engineering design teams, capstone design teams, capstone design course, engineering education, design team effectiveness

1. Introduction

Engineering design teams have been recognized as essential contributors to corporate effectiveness. There is strong evidence that the performance of multi-disciplinary, cross-functional engineering design teams strongly influences successful new product development and organizational performance [1, 2]. Educational institutions have invested great effort into developing approaches to better prepare engineering students to become active contributors to engineering design in their future careers. As a core part of this development, undergraduate engineering students typically complete a capstone design project as a requirement from the Accreditation Board for Engineering and Technology (ABET). Educators and industry stakeholders consider the capstone experience as a critical step in preparing students for their future jobs. Capstone design projects may be completed individually or as part of a group depending on the course or the overall program design. Since teamwork is considered a critical skill to succeed in the professional world, an increased number of capstone design courses require students to accomplish a design project in a team setting.

According to Ertas and Jones, engineering design involves a number of steps including research, conceptualization, feasibility assessment, establishing design requirements, preliminary design, detailed design, production planning, tool design, and production [3]. Disciplines such as software engineering, mechanical engineering, industrial and construction engineering typically involve complex product design requiring a multidisciplinary team. Thus, mastering teamwork skills and knowledge of engineering design process are both critical outcomes for engineering students. In this paper, we will review prior research on capstone design teams from three major engineering
Zhou and Pazos

education journals. We will identify the major issues faced when designing and managing a capstone course and the factors that drive the effectiveness of capstone design teams in engineering. We will conclude by providing some recommendations regarding capstone design teams from the perspective of managing team processes.

2. General Issues Faced in Capstone Design Courses
This section identifies critical elements related to the management of capstone design team projects.

2.1 Project selection
Engineering programs typically establish specific procedures to guide capstone projects. Among those procedures, project selection is a critical aspect that capstone design courses have to account for [4]. Prior research suggests that the topic of the project needs to be carefully selected to provide the appropriate level of challenge and to promote student engagement and motivation [5]. Delson proposes a set of criteria for the selection of capstone design projects including: 1) provide an achievable and tangible objective; 2) promote creativity in the design solution; 3) provide students with an external source of feedback; and 4) define meaningful intermediate milestones [6]. In addition, ABET also provided some guidelines for engineering capstone projects including: 1) promote the development of student creativity, 2) use of open-ended problems, 3) use of design methodology, 4) incorporate formulation of design statements and specifications, 5) provide opportunities to evaluate alternative solutions, 6) evaluation of design feasibility, 7) consideration of economic factors, safety, reliability, aesthetics, ethics and social impact [7]. Special attention should be focused on topic selection because it is known to impact student motivation [5].

2.2 Team Formation
One frequently cited element of capstone design courses is the composition of the teams. Usually teams are formed either through student self-selection, random assignment or systematic instructor assignment. Paretti and his colleagues discuss the implications of self-selection versus systematic assignment of team [8]. Each of these three methods have different strengths and weaknesses and their efficacy will depend on the learning objectives and course design. For instance, students who select their own teammates tend to feel more responsible for their final performance, which in turn can enhance trust, cohesion, and cooperation of the teams [9, 10]. On the other hand, systematic instructor assignment provides instructors with more control over various criteria such as students’ work experience, personalities, educational background, GPA when forming a team. A group of researchers has developed a web-based and freely accessible tool that helps instructors to form teams based on a flexible criteria [11]. This approach allows faculty to balance the skills and abilities of team members and is found to lead to improved team outcomes [12]. Random assignment might be the most frequently used method because it takes less time and effort to form a team. However, randomly assigned teams do not necessarily result in balanced skills or personalities among team members [13] and can result on feelings of unfairness that can affect team performance [14]. On the other hand, self-selected teams may lead to excessive homogeneity [15] and convergent behaviors [16] that can undermine team outcomes. Systematically assigned teams can be more time-consuming but there are existing tools to support and automate the process that significantly reduces that preparation time [11, 14]. Prior research suggests that capstone instructors should evaluate the strengths and weaknesses of each formation strategy along with the learning objectives when selecting a specific approach to team formation [8-12].

2.3 Learning Goals and Skills Sought
A third issue that capstone instructors often struggle with is whether to focus on the final project outcomes or emphasize the process itself as part of the learning experience. Paretti and his colleagues discuss this issue acknowledging that instructors have difficulty meeting both objectives [8]. According to Howe and Wilbarger, in courses not supported by outside sponsors or customers, most capstone instructors emphasize a learning experience through processes such as communication, planning, decision making. Conversely, in courses that involve outside sponsors or customers, a focus on the final project outcomes is largely emphasized [17]. However, industrial supported projects are difficult to obtain and not always available to students. Although the learning experience and the process is important in capstone design projects, most authors agree that the final outcome is critical since the ultimate goal of a design course is to prepare the students for their future engineering jobs. Balancing these two competing objectives within the time constraints of capstone courses is of critical importance for a successful capstone experience.

Another issue in capstone design courses is whether to emphasize technical practice or professional practice [8]. Technical practice refers to the students’ ability to deploy the technical knowledge needed for problem solving.
Professional practice refers to broader non-technical skills such as interpersonal and communication skills. Instructors might overlook the importance of the professional factors when guiding or coaching students in capstone design projects [18, 19]. However, studies have shown that professional skills should be incorporated into capstone design project curriculum to better prepare students for the professional environment [20, 21]. Some have argued that through systematic assignment, instructors will be able to manipulate the diversity of the capstone design teams and, as a result, help promote the development of interpersonal and communication skills of students [12].

3. Factors Leading to Successful Capstone Design Courses

Next, we review the factors that have been found to contribute to a successful design team experience. These factors will be based on an in-depth review of the articles published on the three major engineering education journals.

3.1 Coaching and Mentoring

Traditionally, most capstone design teams are assisted by instructors. However, most instructors usually act as a lecturer or consultant, which may not provide sufficient instruction or coaching to promote student learning of design and teamwork skills. Taylor and his colleagues have discussed this issue in their research and suggest that the coaching role of the instructors is essential to the success of a capstone design team [22]. Through their study, they point out that coach’s concern for team’s success and coach’s ability to support collaboration and design processes are highly related to the performance of a capstone design team. It has also been suggested that initiating team discussion and using periodic team self-assessments by the instructors can be beneficial for team performance. Their research argues that if an instructor has proper coaching skills, understands the basic design process and teamwork functions, and emphasizes their role as a coach rather than a lecturer or consultant, the capstone design team would be more likely to perform well.

Research also shows that team independence leads to increased responsibility of team members for the project outcomes, which in turn results in better performing teams. This doesn’t mean that instructors should withdraw the coaching role and provide the teams with full autonomy, but instead instructors should remain available for issues related to the design process and leave the decision making to the teams [5, 6].

3.2 Feedback and Evaluation

Peer evaluation is another critical factor to the success of capstone design teams. Williams and his colleagues have conducted research on this subject and find that peer evaluation positively influences final outcomes in capstone design teams [23]. In addition, they point out that if peer evaluation is employed at the end of the project, there will be little effects of it. Instructors should structure and implement peer evaluation periodically throughout the capstone design project, which is proved to be more valuable and motivating to the students.

Capstone design projects are usually evaluated at the end of the term in order to measure the performance of the students. However, Lau, Beckman, and Agogino suggest that instructors who implement effective evaluation at the mid-point of the project would increase the team awareness of their performance and lead to more self-correction and motivation during the second half of the project [24]. This is also supported by research from Agogino, Song, and Hey suggesting that mid-term feedback to the capstone teams is positively related to final team performance [25].

External feedback provided by the customer or project sponsor is also linked to improved design team performance [5, 26]. External feedback provides a different perspective on the design process and product, and thus offers the team a valuable resource for enhancing their outcomes. However, most of the capstone design projects are not sponsored or connected to outside customers. Therefore, we suggest that if corporate sponsors are not available, external feedback from an industrial subject matter expert might be valuable.

3.3 Deadlines and Milestones

Aside from the factors discussed above, setting up appropriate deadlines and milestones for capstone design teams may also improve team performance. Delson argues that deadlines can stimulate team development and teams who successfully achieve milestones build confidence and trust within the team. It is suggested that deadlines and milestones can help the team accomplish more challenging project objectives [5]. Even for those teams that fail to meet some milestones, they can serve as an early warning sign and a motivation to catch up with others.

3.4 Development of Team’s Shared Understanding
In Hill, Dong, and Agogino’s study of the effects of shared understanding on design team performance, their findings suggest that a higher degree of shared understanding leads to higher quality outcomes [27]. Based on their study, Agogino and his colleagues conducted additional research indicating that high performing teams usually have high variation in shared understanding throughout design stage. Shared understanding would typically start low and improve during the design process and it should be high towards the end of the process. A decrease of shared understanding during the later stages of design is very likely to be disruptive of the overall process [25]. Therefore, it is suggested that design teams should focus on building a shared understanding of the design project at the early stages to avoid painful disruptions during the more advanced stages of the design process.

Team building exercises are believed to be effective, especially at the team formation stage [5, 28]. They can be used as icebreaker, to facilitate communication among team members and to build trust and shared understanding within the team. Team building exercises can also be employed for other purposes such as helping the students learn about teamwork skills.

For most engineering design activities, sketches are one of the indispensable components of the process. During the past ten years, researchers have looked at the relationship between the role of design sketches and team performance [29]. Through the analysis of sketches, research suggests that a greater number and greater detail in sketches are positively related to the design team performance [25]. Furthermore, high performing teams usually have an increasing number and more detailed sketches towards the later stages of the design. One of reasons is probably because detailed sketches may promote team’s shared understanding on the design project. Thus, more attention should be addressed to the design sketches both by the instructors and students.

3.5 Team Diversity
It was mentioned in a previous section that team members’ educational background an important criteria that needs to be considered by instructors forming capstone design teams. Instructors usually assign students from different educational background to form a capstone team in order to facilitate the critical thinking and interdisciplinary cooperation. Compared to homogeneous teams, interdisciplinary teams may benefit from a wider vision and diverse perspectives, which is proven to enhance team performance. Terpenny and his colleagues found that “interdisciplinary teams produce higher quality results and value both the collaboration as well as the opportunities opened by working with people from another discipline” [30]. Thus, it is worthwhile for the instructors to consider this factor when assigning capstone design teams.

When instructors assign students to different capstone teams, gender diversity might be an additional factor to consider. One study suggests a positive relationship between gender diversity and performance of capstone design teams [24], indicating that a higher number of women in the team might facilitate the social interaction and thus enhance the working relations within the groups. These interactions can lead to enhanced work outcomes [32, 33]. However, further research is needed to enhance our understanding of the relation between gender diversity and team performance.

4. Discussions and Implications
The first two issues that an instructor faces in a capstone design course are project selection and team formation. Project selection is known to influence team motivation, learning experience and performance of the students [4, 5]. Therefore, it is an important factor that instructors should consider. With regards to team formation, systematic instructor assignment is suggested to be more conducive to an enhanced team learning experience and better final outcomes. Nowadays, a number of web-based tools have become available to facilitate multi-criteria team assignment, saving a great amount of time for the instructors [11]. Thus, systematic assignment for the team formation is highly recommended. Besides these two issues, the learning objectives of capstone design projects also deserve attention. Most of the current capstone projects emphasize process-related learning outcomes as supposed to actual design outcomes. However, the actual outcome of the project is also important, as it is a key part of an authentic design experience. As a result of focusing on outcomes, we see increased student confidence in future engineering design activities. In addition, professional skills such as team building, communication, and conflict resolution need to be emphasized as well since the ultimate goal of the capstone design course is not only to acquire design knowledge, but also to prepare the students for their future engineering careers. Instructors should put more effort on balancing these competing goals and practices within the time constraints of the capstone design projects. This paper’s comprehensive evaluation of the key factors driving capstone project success is aimed at supporting this balancing act.
Besides the issues discussed above, factors driving successful outcomes are also worth the attention of capstone instructors. Instructors that take the role of a coach rather than a lecturer contribute to increased success of the capstone project. Furthermore, giving students enough independence while still making appropriate interventions is highly suggested by our findings. Different sources of feedback should be provided to students and appropriate milestone and deadlines need to be established to facilitate the project process. In addition, both the instructors and students should pay much attention to the importance of team building exercises and design sketches to enhance shared understanding within the capstone design teams. Finally, when assigning the capstone teams, interdisciplinary and gender diversity needs to be considered by the instructors to help support the learning experience and performance of the capstone design projects. The findings of this paper are especially relevant for the discipline of industrial engineering, which typically involves a multidisciplinary and systemic approach to design projects requiring a focus on process as well as outcomes. In this paper, we review important considerations when designing and managing a capstone course and we uncovered the most prominent indicators of successful capstone design teams from the engineering education literature. We hope that the results of the paper can benefit faculty who are developing and managing capstone design courses.

References:

Zhou and Pazos


