

Pedagogical Approach of Single-Semester Industry Engineering Capstone Course

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While Capstone courses are typically designed to provide a cumulative review of an engineering curriculum with practical application, they should also play an integral role in engineering students' transition from academia to industry. One way to achieve this is to provide students with industry problems to solve as a team over a single semester. Partnering with industry sponsors, Iowa State University's department of Industrial and Manufacturing Systems Engineering gives students the opportunity to execute real-world, industry projects with condensed timelines to immerse students into an environment similar to what they would experience when entering full-time into the workforce. Providing a structure with key milestones supports a logical approach to identify a solution while ensuring timely and complete execution of the project. The benefits of not only having an industry project but condensing the execution to a single-semester include logistical consistency and business relevancy. This paper outlines the overall course organization of a single-semester Capstone course with industry sponsored projects and benefits to both the students and clients of this pedagogical approach.

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Introduction

It is recognized industry involvement in Capstone projects is beneficial in enhancing the student experience with many institutions leveraging industry relationships to provide scenario-based learning projects, outside perspectives on a pre-determined projects through participation on an advisory board, or projects for student teams to lead design, analysis, and implementation¹. This collaboration between the students and industry sponsors (clients) can help to bridge the gap between academia and industry and ease the transition post-graduation, especially when students are tasked to solve industry problems and can see the live impact of their efforts to the project area. Unlike traditional case study projects, these projects are active opportunities within a client's organization needing to be improved or resolved. Several challenges arise when considering this approach over a multi-semester time horizon given constantly evolving industry trends and the importance of team continuity, both from a student and client perspective, when using industry projects as an experiential educational tool.

The Industrial and Manufacturing Systems Engineering Capstone course at Iowa State University currently pairs teams of four students with unique, pre-scoped, industry projects primarily focusing on improvements relating to manufacturing processes, operations research, and ergonomics. Clients present a problem, target objectives, and desired deliverables to the

student teams at the beginning of the semester. Client objectives include, but are not limited to, improving efficiency and throughput, reducing defects, reducing waste (i.e., transportation, inventory, etc.), and reducing potential for injury. Examples of deliverables could include a new warehouse layout, prototypes of fixtures, optimized medical hub locations, shadow boards, and redesigned ergonomic work standards; all groups are also expected to provide an economic impact of their project. The course is conducted over a single semester (Fall or Spring), as opposed to a two-semester approach, to address timeline challenges and emulate the industry experience, including time constraint pressures and critical milestone timelines, in a supported academic environment. The course organization requires a standard, structured approach for the project, serving as a key tool for student teams to use in their problem-solving method, while course milestones ensure regular progress and feedback loops to drive the project to achieve the semester timeline. The condensed timeline addresses several key areas of interest around logistical consistency and business relevancy to ensure students get the most out of the Capstone experience. These elements ensure a robust pedagogical approach to allow students to successfully achieve the course outcomes.

Course Organization

The overall course organization for the single-semester Capstone is important to ensure successful

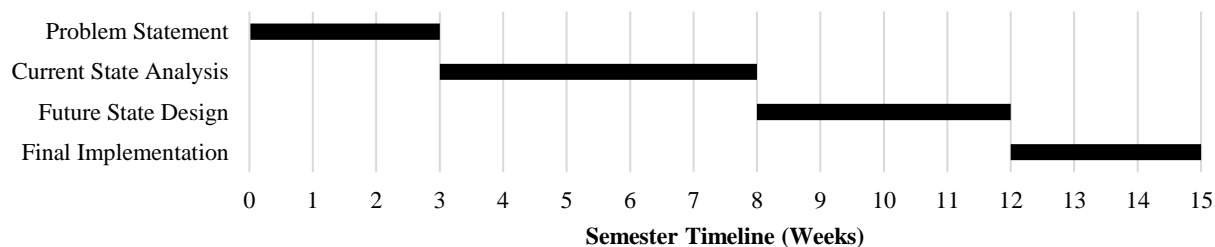


Figure 1. Key project milestone timing during semester

outcomes for both students and industry clients. Ensuring a standard structure is in place is important to any industry sponsored project^{2,3,4}, but it is especially important with the condensed timeline in a single-semester course. The course coordinator identifies an appropriate number of industry sponsors to accommodate teams of four students for each semester with unique, pre-scoped projects. Pre-scoped projects identify the opportunity the client sees to improve their business without necessarily defining a specific design outcome to address the opportunity. Each semester is 15 weeks in length with final course deliverables consisting of a written report, oral presentation to the client, and poster presentation, which is open to the public, in addition to agreed client deliverables associated with the project. The target economic impact for each project is \$100,000.

Between site visits and course work, student teams are expected to spend 900 hours cumulatively on the course. One-hour instructional periods are held weekly to review key concepts from course prerequisites tied to practical industry examples, including work sampling, time studies, value stream mapping, and ergonomic assessments. An industry experienced instructor meets with the student teams three times per week during a scheduled two-hour lab to review project status and provide coaching on a variety of topics, including industry best practices, conflict management, and technical communication with stakeholders. Student teams are expected to work with their clients outside of the regularly scheduled course time, including client meetings, site visits, presentations, data collection, and implementation of the final design⁵. Clients are typically located within three hours from campus; those located near campus will experience shorter, more frequent visits from students, while those further from campus experience longer, less frequent visits. Student teams can choose to travel individually or as a group and should schedule visits around any other courses they have.

Students are required to submit reports, aggregative in nature, corresponding with prescribed milestones to ensure completion of the project in line with the course schedule. These are reviewed to provide feedback to the student teams and are the foundation for the remaining course deliverables. Key milestones (Figure 1) include:

1. Problem Statement
2. Current State Analysis
3. Future State Design
4. Final Implementation

Problem Statement Milestone

The Problem Statement milestone concludes at the end of the third week of the semester. This milestone requires the team to communicate with the client to clearly understand the expectation of the project outcomes for the semester to facilitate in defining the problem, outlining objectives and deliverables, identifying assumptions and constraints, formulating a project timeline, and assessing initial potential impacts, including economic impact. This stage also emphasizes building a client relationship. No data is collected at during this milestone.

Current State Analysis Milestone

The Current State Analysis milestone concludes at the end of the eighth week of the semester. This milestone requires the teams to validate information from the Problem Statement through data collection to further refine their scope, understand any associated processes, quantify the magnitude of the problem, and identify root cause. Once results from the data collection are analyzed, project outcome expectations are revisited and next steps for design are agreed with the client. The students are expected to engage key stakeholders at their industry sponsor during this process to build further relationships to leverage during the implementation stage.

Future State Design Milestone

The Future State Design milestone concludes at the end of the twelfth week of the semester. This milestone requires teams to propose solutions to their assigned projects giving the client a minimum of two options to choose from for final implementation with associated costs and benefits of each. These options align with the agreed deliverables and are formulated in collaboration with key operators of the process. For example, if a new plant layout to improve flow of a work cell is a key

deliverable, the team will work with operators of the area to identify options meeting the original objective. At the end of this milestone, the student teams must get agreement from the client which solutions to implement as part of their deliverables to close out the project.

Final Implementation

The final written report deliverable due at the end of the semester requires teams to compile all milestones into a comprehensive report reviewing the complete process of executing their project with the addition of any final implementation activities following selection of the Future State Design solution by the client. Depending on the scope of the project, the team may not be able to fully implement the design, so handoff documentation must be provided by the team to the client including next steps to complete implementation; this is common for projects proposing locations for a new facility, modifying plant layouts, or implementing new software. In many instances, the student teams are able to fully implement their changes, including shadow boards, standard work, rapid prototyping of fixtures, and preventative maintenance procedures. The feedback from graded reports and presentations from the prior three milestones should be taken into account by the team and corrected prior to inclusion in the final written report.

The student teams must complete an oral presentation with their client to review the project holistically, including next steps and future improvements. The clients provide the final grade for the student group and an evaluation of the overall economic impact expected from the project (one-time or recurring) and the percent of the proposed solution to be implemented for use by the department. A poster presentation session, open to the public, is held with all student teams. This is scheduled between oral presentations to allow participating industry sponsors to view other projects and generate ideas for future projects.

Discussion

The course organization described supports an aggressive single-semester timeline of an industry Capstone project while providing the resources essential for completion of the project within the course timeline. Key benefits of the single-semester approach include logistical consistency and business relevancy.

Logistical Consistency

For courses spanning across multiple semesters, there are several logistical challenges that can arise. Ensuring the project team is consistent is important to build upon the team dynamic and prevent disruption to process flow.

In a two-semester format course scheduling conflicts, internships, and other unforeseen circumstances could cause a team member to drop the second semester of the

course. This not only puts the student at a disadvantage to complete the requirements of the curriculum, but it causes the remainder of the team to be short resources and could impact the overall schedule or quality of their implementation plan. It is also important to note the stages of group development will be interrupted reducing the effectiveness of the team to perform optimally⁶. While a student who had missed the second semester could be added into an existing team, the learning curve for the new student to get up to speed having not been involved in the first semester could cause a burden on the team dynamic slowing the continued progress of the project. For a multi-semester course, it is important the student has each semester sequentially with the same team to ensure continuity of the project and ensure engagement in the full design process from start to finish, including managing team dynamics. By condensing the course into a single semester, this obstacle can be minimized or avoided completely.

From an industry sponsor standpoint, a longer-term project puts members of the client team at risk for changing roles, whether it be transformational business changes or continued development and career progression. According to a recent survey, the median years of service for an employee at a single employer over the past decade has decreased by 25% to circa five years⁷, and 22% of workers surveyed expect to move roles in the next six months⁸. It is important for the client to have consistent representation of individuals who are knowledgeable of the project to best support coaching the student teams. Likewise, assigning both an experienced and unexperienced engineering representative to help coach the student teams allows the industry sponsor to foster development of key leadership qualities to upskill workers to grow into future management positions in a short time period. Consolidating into a single-semester to promote team consistency will prevent interruption to the flow of the project and allow the students and clients to fully capitalize their Capstone experience.

Business Relevancy

Industry is constantly evolving. Projects implemented in condensed time scales are essential to give businesses the edge against the competition and ensure the benefit can be realized before other changes cause the current project to become irrelevant. Industry partners often use structured, accelerated improvement techniques, such as Kaizen Events⁹ or Sprint Events^{10,11}, to quickly define problems and implement solutions in a span of a financial quarter supported by cross-functional resources across the business in addition to their traditional duties. This accelerated approach requires companies to have robust problem definition and scoping to increase organizational efficiency and execution of projects. This is replicated in the single-semester Capstone approach.

Companies are often under time constraints to implement fixes to problems, especially those impacting their bottom line, which adds pressure to those working on the project. By having a very clear and condensed timeline adding a sense of urgency, students get to experience the pressures of the workplace environment and practice maintaining their professionalism and integrity in a controlled, safe environment; any lapses can be viewed as a learning experience to help them grow individually to prepare for the next step in their careers. This requires focus and commitment to drive the project and see it through to completion with minimal delays due to rework or process inefficiencies. By simulating this workplace environment in the Capstone course, students can develop effective behaviors and techniques to address this when encountered in their future careers.

By outsourcing projects to the Capstone program, the client not only saves critical resources within their organization to manage the day-to-day tasks, but they can gain outside perspective on potentially lingering issues in a low-risk environment. Additionally, costs can be minimized compared to professional consulting services or short-term headcount increases to support the project beyond the Capstone fee, which would have a significant impact for small, local businesses participating as industry sponsors. Developing businesses sponsoring a Capstone project are also given the opportunity to better mature project scoping capabilities, including problem definition and timeline estimates, with coaching from the Capstone instructors to enhance and upskill the overall capability of their workforce to scope activities in the future. While these are all relevant benefits regardless of the length of the course, the condensed timeline will allow the sponsor to realize the economic benefit of the cost avoidance or savings earlier on and potentially implement a greater number of projects in a shorter period of time.

Conclusions

The single-semester Industrial and Manufacturing Systems Engineering Capstone course at Iowa State University is organized to enable efficient execution of industry projects. Benefits of this pedagogical approach can be observed for both the students and industry sponsors. The structure enables student success and offers an experience to prepare them for industry work. Key benefits shared between the students and clients include logistical consistency and business relevancy. By pairing teams with industry sponsors, the course is not only able to provide quick turn benefits to enhance the educational experience for students, but it supports local clients to grow the capabilities of their business and employees.

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