Interdisciplinary Collaboration in Capstone Courses

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Work in Progress – Designing a Capstone Course Towards Effective Collaborative Behaviors in Interdisciplinary Environments

Abstract

Senior capstone classes are unique and crucial experiences for undergraduate students, in that they provide long-term, often synthesis-based projects in a collaborative environment. Yet, an overwhelming majority of programs do not provide students with the chance to work cooperatively across disciplinary lines. Those that do typically only allow for interaction between groups within the same overarching discipline such as Mechanical or Electrical Engineering. Ideally, the capstone experience is meant to foreshadow the type of interaction and work that a student will engage in, easing their transition into the work environment following graduation. In industry, engineers are expected to work collaboratively with experts in several technical and non-technical domains. Subsequently, capstone classes are lacking the ability to prepare undergraduate students for membership on the interdisciplinary teams that exist in workplaces within the United States and abroad. As such, the purpose of this paper is to describe the process of creating and subsequent plans for implementation of an interdisciplinary capstone course at a large research-intensive institution in the Southeast US. The challenges associated with developing a course that meets the need of each disciplinary capstone experience and spans the boundary of different approaches to pedagogy, knowledge structure and learning will be explored as well.

Background and Objectives

One of the most common complaints among recruiters of engineering graduates is a failure of universities to properly prepare their students to collaborate within a diverse workplace environment [1], [2]. Students typically complete most of their coursework within their discipline of choice, with few opportunities to work with students in other majors, at least in an academic setting. This trend includes the capstone courses that conclude many undergraduate pathways [3]. These capstone programs are intended to provide hands-on, project-based experiences with problems analogous to industry assignments. Capstone courses can take on several forms under these guidelines [4].

At the institution where this study is being conducted, capstones often fall into three broad categories: 1) college-based, where the projects are derived from college sponsored activities and engagement, 2) research-sponsored, where projects are based on research projects being conducted by faculty in the respective departments and, 3) industry-sponsored, which involve direct interaction with company partners. The companies provide problems that arise in their day-to-day operations that teams of students make an effort to provide solutions to. These types of courses are intended not just to allow students to attempt to solve complex, often open-ended problems, but to allow them to develop skills regarding project management, professional presentation and communication, and effective collaboration within their project team [5]. However, most capstone courses in engineering disciplines are monodisciplinary – that is, all work is done within a single engineering major or a single specialization within that major [3]. This limitation hinders students once they arrive in their work environments and are required to

interact with colleagues from other departments, teams, or even diverse educational backgrounds within their own team.

Several engineering programs at institutions around the world have begun to implement interdisciplinary capstone courses in pursuit of a variety of goals [6]–[9]. These capstone classes take on two primary forms: multiple engineering disciplines and a combination of engineering and non-engineering disciplines. The course being investigated in this study is an example of the latter, with teams composed of students from a variety of unconnected disciplines. It is from this diversity that the phenomenon of interest emerges. Students harbor beliefs about what their major or field of study indicate about themselves, and likewise what other students' decisions say about them. For example, it is widely accepted that many engineers believe nontechnical skills to be easy and subsequently less valuable in the grander scheme of things [10]. A belief like this could potentially impact the way that an engineering student interacts with a teammate in a nontechnical major like political science or creative writing. By encouraging students to collaborate with a diverse team in a capstone environment, they are given the chance to experience interdisciplinary interactions prior to entering the professional world. Further, observing and gaining an understanding of the impact that this pre-employment experience has on students can help engineering education researchers (EER) understand the role that diverse teams, particularly in the capstone environment, can have for engineering students in the development of their collaborative abilities.

In the long term, this study seeks to better understand how the social norms that are present in interdisciplinary teams influence the development of effective collaborative behaviors. These behaviors can be considered as belonging to a larger grouping of skills, sometimes called "meta-competencies," that have become an increasingly important part of what employers look for from engineering graduates [11]. However, this paper will focus directly on the curriculum design of an interdisciplinary capstone course. In order to ultimately investigate the role of interdisciplinarity, it is first important to understand how the particular context being studied came to be. We will be exploring how the capstone class was developed from ideation to implementation. The composition of students in the class will be examined, alongside the variation in the capstone experiences for each of their respective disciplines. Finally, the role that this course's design plays in bringing together the separate capstone requirements for various disciplines and satisfying the different requirements will be discussed.

Program Development

The interdisciplinary capstone course being investigated in this study is the pilot run of a newly developed capstone option at a large public Mid-Atlantic university. The guiding philosophy behind its design is that of the "t-shaped engineer," which advocates for a combination of both deep disciplinary knowledge and the ability to work with professionals from a variety of fields [12]. Additionally, the increasing emphasis on the National Academy of Engineering's Grand Challenges and similar problems which require input and solutions from experts in many fields has served as a catalyst for the program's development [13]. Existing research has also indicated numerous purely educational benefits to working on interdisciplinary teams, including

developing the ability to effectively collaborate with experts from other fields and exposure to methods and instrumentation that might not be taught in one's own discipline [14].

Current State of Capstone Collaboration at Study Institution

In 2015, our study institution launched an initiative aimed to promote and sustain interdisciplinary curricula and collaboration. However, despite the strategic goals associated with this initiative, the reality is that most faculty/instructors and students remain more or less siloed, whether within discipline, department, or college. For example, as mentioned before, students in senior capstone classes do not usually collaborate with other students outside their areas of specialization. Furthermore, students rarely collaborate within their own colleges. At the institution, there are 14 different engineering majors, and while each specific major offers its own capstone (usually 4 or 5 students working with one another within their own majors), these students rarely, if ever, collaborate with other students outside their majors. While there are obvious benefits to this current framework – sustained focus in a single discipline allows students to gain depth in a single area of expertise, which allows instructors to manage predictable structures and outcomes – students have few opportunities to cooperate or dialogue with others outside their own school, much less outside their own discipline.

Likewise, faculty have largely and historically *not* been rewarded or recognized for collaboration. While examples of partnerships exist between individual faculty from different disciplines, in most cases the courses are a special section that is offered for a semester or two rather than an integrated part of the curricula. These courses are often abandoned as one or more of the faculty members is tasked with additional responsibilities or due to a shift in priorities. Because it has largely been the focused efforts of the individuals rather than at the department or college level, their role is not backfilled, and the course goes away.

Capstones for Each Discipline

For the pilot run of the capstone class being studied, four colleges were involved. Faculty from the colleges of Industrial Design, Engineering, English, and Entrepreneurship collaborated to design the process. At the initiation of this process, faculty from each discipline sought to work together to develop, instruct, and ultimately assess the course throughout its duration. They planned to act as an example of effective interdisciplinary collaboration for the students as they guide the teams through their respective tasks. The design process of the course began with a comparison of the strengths and weaknesses of existing capstone courses in each of the represented disciplines, as well as a consideration of the challenges, risks, and benefits of shifting to an interdisciplinary collaborative approach. These considerations were recorded and combined into a proposal which was subsequently presented to and approved by the university curriculum committee for implementation in the Spring 2019 semester.

The current capstone courses in each discipline have similarities in structure but have different outcomes and content requirements. The table below models a sample of these differences.

Table 1 – Summary of capstone course requirements for disciplines involved.

Disciplines	Number of credits per semester	Final Project	Additional Material/ Important steps	Group vs Individual
Design	6	Looks like or works like prototype along with a process book and presentation	Problem identification, iteration, Concept generation, Making design decisions, Final proposal, presentation	Group or individual
Engineering	3	Modelling, Technical reports, Senior Design Expo which includes project exhibits and poster presentations	Integrative experience that captures students' ability to effectively plan, manage and implement technical projects using the engineering design process	Group
English	3	Portfolio	Proposals, Drafts, Workshops, Final drafts/exhibits, Reflection	Individual
Entrepreneurship	3	Pitch, Presentation evaluated by outside experts	Problem validation, Business model generation, Team formation, and Feasibility analysis	Group

As currently designed, the interdisciplinary capstone course has two distinct phases. The first is a sort of "set-up" phase, where students were introduced to the concept of the course. Teams were formed based on student interests with care to ensure diversity on each project group. Several important topics, including collaboration techniques, brainstorming methods, intellectual property rights, and problem definition were covered in advance of teams beginning work on their projects. It is also during the first phase that students were given the timeline and list of necessary deliverables for their projects, which will be carried out in the second phase. The majority of the time will be spent in the latter section of the course, so as to not shift the focus of the capstone experience away from the design and execution portions. This project phase has regular deliverables so that the teaching faculty in charge of the course can monitor teams as they progress through the semester. Teams were required to submit weekly progress reports for their projects, as well as a monthly project review with faculty, mentors, or clients on the project. The following table summarizes the course design as well as outlines the level of responsibility of faculty and students.

Table 2 – Description of course design and respective roles.

Semester	Students and Faculty	Support staff
Fall	• A cross listed course designed to connect students from multiple disciplines so that they work on the same issue/project. At the end of the course, these student teams will present a project that they will work on in Spring semester as their capstone. • The class will also be provided a stipend for successful student teams for the spring semester projects	• A dedicated person will research the existing check sheets in each discipline, ensure that the "topics class" can be cross listed and will create the course description that can be shared appropriate curriculum committees for approval. The course needs to be ready for enrollment on first day of Fall sign up. • The course description should be designed so that it can be connected to disciplinary check sheets. The ideal scenario would be to replace a required course in each major with this cross listed course.
Spring	• A fifteen-week long capstone project, that is undertaken by the students in place of the capstone in their respective disciplines. • The student teams work together in sandbox studios/the media building studios and are advised by a group of faculty from participating disciplines. • Weekly team presentations are designed to integrate learning objectives from all of the participating disciplines. Each team prepares a presentation where the structure is provided by the advisors. The guidelines for this course have been designed in a way that the final project book can be used to extract discipline specific sections so that it can be compared with a project done in the traditional manner.	• A fifteen-week long capstone project, that is undertaken by the student teams will be worked on as a team project. Each team will have a budget to purchase materials and supplies. • The student teams work on these projects as experts with the end goal of a comprehensive project report. • Bi-weekly team meetings are facilitated through C&I resources and the meetings and discussions take place in the sandbox studios. • The teams will have a three-week review, a seventh week review and a final capstone show at the end of semester. • The final showcase will be attended by representatives of our corporate partners and the presentation as well as the process book will be provided to the professional reviewers one week in advance.

Current Enrollment and Projects

There are 28 students enrolled in the course representing three departments: Industrial Design, Computer Science and Business. There are seven teams comprising of four students each. The following table illustrates the breakdown of students and how the groups are structured.

Table 3 – Breakdown of discipline composition in the course and in teams

Departments represented	Industrial Design	Computer Science	Business
Number of students per discipline	7	14	7
Number of students per group	1	2	1

A collation of design skills independent studies was created to account for the differences in capstone credit requirement for the three disciplines involved. Meaning, since the industrial design capstone is allotted six credit hours in the Spring semester and the other groups, business and computer science, are allotted three – students are encouraged to register for the design skills independent studies. In terms of in-class time, the combined group of students meet twice a week for three hours in the studio with the additional three hours spent working on their independent study tasks. Currently, each group of four is working on creating a solution to address one of the following topics:

a. Aging in place
b. Autonomous Vehicles and Us
c. Design for Empowerment

The teams have access to design shops and studios, 3D printers and external prototyping agencies, three faculty advisors representing each discipline and other stakeholder expertise.

Future Steps

Current and future project activities are designed around three specific goals and will seek to achieve these goals by means of related and measurable research questions:

Goal 1 – Evaluate the current design and implementation of a connected capstone course
RQ1.1 How is the connected capstone course currently being taught?
RQ 1.2 How is the division of work managed among instructors and students?
RQ 1.3 What are students and instructors' perceptions of the collaboration in the connected capstone setting?

Goal 2 – Identify established norms associated with effective collaboration in multi-disciplinary design teams
RQ2.1 How do students enrolled in a connected capstone course problem solve?
RQ2.2 What overt collaborative behaviors do students exhibit as they engage with their teams during the studio session?

Goal 3 – Systematically study multi-disciplinary capstone courses across the United States
RQ3.1 What is the current status of multi-disciplinary capstone courses in higher education institutions?
RQ3.2 How do capstone instructors characterize their process for evaluating students as collaborators in multi-disciplinary capstones?

The above-mentioned research goals and questions will be answered through a series of two consecutive phases. A pilot study is already being conducted to collect preliminary data about the course from the students and instructors. In the first phase of this study, research goals one and two will be addressed through the use of the pilot data. Data will be collected in several forms. First, shortly after teams have formed and had the chance to become acquainted with their projects, observations will begin. These observations will be oriented towards examples of effective collaborative behaviors, with particular focus on interactions happening across disciplinary lines. Towards the latter half of the semester, interviews will begin with students and the faculty running the course in the interest of diving deeper into individual experiences that might not be observable, as well as the types of social norms that students and faculty might harbor. Finally, there will be a comprehensive analysis of course documents to investigate how the previously explored design considerations manifest themselves in the course itself. Data collection will be guided by the Reasoned Action Approach (RAA) framework to determine what influence, if any, established social norms of collaboration like notions of authority, problem definition and what passes for an acceptable solution to a given problem have on team members' interactions within an interdisciplinary capstone class.

Following the analysis of the observation, interview and artifact data, phase two will encompass an assessment of multi-disciplinary capstone courses in institutions across the US. This information will be gathered from a systematic literature search, contacting the executive committee of the Capstone Design Conference and utilizing the networks of the project team members. Where applicable, instructors of these courses will be phone interviewed and requests made for their course documents in order to answer the research questions associated with third research goal.

The anticipated outcomes from this study will provide guidance for other educators interested in blending disciplines that are otherwise disconnected. This work will result in highlighting how a capstone experience can be created that satisfies the capstone requirement across multiple unrelated disciplines. While the current connected capstone course was designed with the four involved departments in mind, a future goal is to provide the opportunity for collaboration between or among any number of disciplines. One main anticipated project output is a model for a multi-disciplinary capstone course that can be implemented across related and unrelated disciplines at higher education institutions.

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