Supporting Multidisciplinary Programs through Common Language and Modular Instruction

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Multidisciplinary capstone design programs provide unique opportunities for students and, often, unique challenges for course faculty. This paper describes efforts at Colorado School of Mines to maintain a successful, multidisciplinary capstone design program serving the civil, environmental, electrical, and mechanical engineering programs at the university. Two key efforts are described: the first is an ongoing effort to develop a common design assessment language across the college; the second is to provide modular, department specific resources to students in the multidisciplinary program. Both efforts have been well received by faculty and students and future work is in progress to refine and assess the efforts presented.

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Introduction

Within the engineering community it is widely recognized that many of the grand challenges which are facing society, now and in the future, can only be met by multidisciplinary approaches. At Colorado School of Mines (CSM), the Capstone Design experience has been crafted explicitly to enable unique, multidisciplinary projects. The mix of disciplines, combined with institutional pressures, have led to challenges within the multidisciplinary program. This paper describes the challenges, and presents two ways in which these challenges are being addressed.

Program Overview

The Capstone Design Program at CSM is part of the College of Engineering and Computational Sciences (CECS) required course sequence for students in the Civil, Electrical, Environmental, and Mechanical Engineering degree programs. Each semester over 350 senior students engage with more than 50 unique, client-driven projects.

The Mines Capstone Program is a two-semester sequence (six credit-hours in total). Students are assigned to teams which are tasked with addressing a provided design challenge. Teams are composed of 5-8 students and remain together for the entire experience. Some examples of ongoing projects include civil and electrical engineering students collaborating with an industry partner to design an electrical substation and environmental engineering students working with mechanical engineering students to develop a unique waste reuse system for an NGO.

Over the course of two semesters, students take a design problem from an initial one-page prompt to a proposed solution. The final deliverables from a project may be either "paper" (e.g. a complete drawing package) or physical (e.g. a working prototype). In either situation the students are expected to define the problem and create a project plan, explore multiple possible solutions to the problem, use decision methods to select the most promising solution, apply appropriate engineering analysis in their design process and finally deliver what was promised. The general flow of the class, along with the key deliverables, is shown in Figure 1.

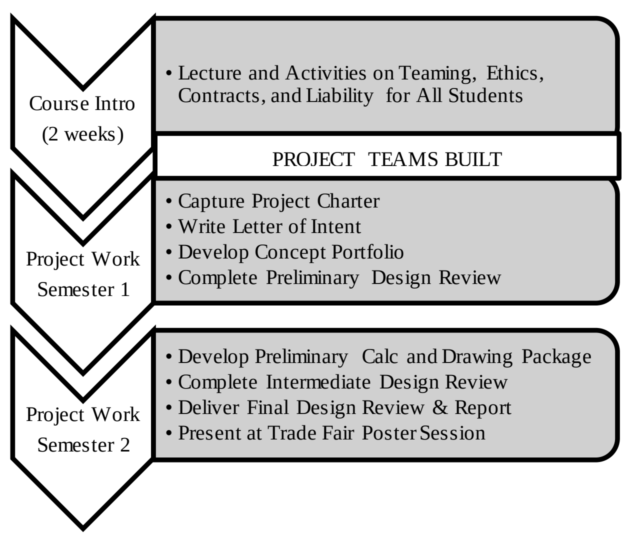

Figure 1 - CECS Capstone Course Flow

Addressing the Challenges of Multidisciplinary Curriculum

CSM has a strong history of multidisciplinary collaboration within the undergraduate curriculum. The Design EPICS program at CSM challenges all freshmen students, and the majority of sophomore students, to complete an open-ended, multidisciplinary project.[1] At the senior level, the School has explored multidisciplinary senior design experiences since the early 1990s.[2]

Built on that foundation, the Capstone Design Program serves three departments, four degrees, which each have their own degree demands, unique industry-specific languages, and departmental expectations. Each department is looking to the Capstone Program to provide the ABET required capstone project, professional practice training, and instruction in multiple discipline specific design tools and techniques to their students.

While the university and faculty believe strongly in the importance of multidisciplinary collaboration, there are several challenges to successful interdepartmental collaboration. Recent feedback from departmental industry advisory panels, and pressure to decrease total degree credit hour requirements have increased departmental demands for the inclusion of discipline specific content in multidisciplinary courses. This push is further reinforced at the capstone level by pending updates to departmental ABET accreditation criteria, particularly for Civil Engineering programs.[3]

Many programs, including past iterations of the CSM program, have used Systems Engineering and Design Thinking as a means to bridge discipline specific language[2,4,5] but the approach has limitations. One major limitation is the previously discussed need to include discipline specific tools and techniques in the course driven by departmental demands. In addition to this, the unique combination of majors in the CSM program have uncovered differences in design perspectives between those programs which primarily serve industrial manufacturing versus those that primarily serve government and construction.[6]

In order to embrace the uniqueness of each degree, and industry, while enabling students to address realistic, multidisciplinary challenges, two primary initiatives have been undertaken:

1. establishing a common design assessment language to measure project outcomes and frame discipline specific tools and techniques, and,
2. implementing modular, student led instruction on discipline specific tools and techniques.

Common Design Assessment Language

It has been shown that multidisciplinary teams often experience more conflict than disciplinary teams and struggle to understand the unique skills that others bring to bear on a challenge.[7,8] Therefore, successful multidisciplinary collaboration requires students to both understand where their unique skills fit within a larger context and to recognize the value of others' skills in addressing that challenge.

Working with faculty from all departments involved, as well as the CSM freshman/sophomore cornerstone design program, a common design assessment language has been developed at CSM over the past year to assist both students and faculty. Based on a series of meetings across the campus, four broad areas of engineering design competency have been identified. The broad assessment areas identified are:

- problem definition,
- problem exploration,
- engineering analysis, and
- implementation.

These areas were broad enough to be acceptable across many engineering departments on campus. Not surprisingly, they correlate closely with many definitions of engineering including Sheppard's definition of what engineers do: "scope, generate, evaluate, and realize ideas" as well as the holistic approach for student assessment proposed by Steiner et. al.[4,9]

Within each broad area, a list of specific learning outcomes has been mapped for the Capstone course sequence and specific course deliverables and content have been developed. The proposed learning outcomes, mapped to assessment area and Capstone assignment are shown in Table 1.

This simple step of defining common language has paved the way for increased coordination with both the cornerstone program and individual departments. In addition, several departments have taken the assessment framework as a call to action and basis for design across the curriculum efforts.[10]

Modular Instruction

Until the Spring 2014 semester, each Capstone design class started with a traditional lecture which combined all degrees and covered generic, high-level design content. Since that time, the program has transitioned to a modular instructional approach which allows students to choose from a menu of options. For the purposes of this paper a module is defined as a 10-25 minute "deep dive" into a specific design tool, topic or technique.

While use of online content modules in higher education is well established,[12,13] the specific application of modular content in the CSM Capstone Program is believed to be unique. Much of what makes an engineering discipline distinct is its language and specific design tools.[11] Therefore, the goal of offering a menu of modules to students is to enable divergence in expertise and learning over the course of two semesters. In short,

Table 1 - Common Language Application

Design Assessment Area	**Capstone Target Learning Outcome**	**Associated Program Deliverable**
Problem Definition	communicate the background, context, and goals of an engineering challenge;	Letter of Intent/Project Charter
	create a project management plan to address an engineering challenge;	
	articulate the functional and/or spatial basis of a design challenge;	Concept Portfolio & Preliminary Design Review
	define a clear set of engineering metrics/constraints for a design challenge;	
Problem Exploration	develop multiple conceptual design solutions to a given engineering challenge;	
	apply the basic concepts of sustainability and equity in engineering practice;	
	utilize decision methods to select the most promising solution that meets constraints and requirements for a given challenge;	Semester 1 – End of Semester Status Update
Engineering Analysis	proactively manage project-level risks and uncertainty;	Project Calculation Package & Intermediate Design Review
	apply appropriate technical knowledge to solve a design challenge;	
Implementation	develop an engineering solution for a given challenge, within constraints;	Final Design Review & Report
	communicate an engineering solution via a detailed design documentation package;	

the modules embrace the unique tools, techniques, and language used in the industries in which students hope to work. Students, given a menu of options, are asked to select those that will directly assist them in their project or future career. In this way, a portion of the program learning objectives are led and controlled by the students.

The initial module topics were simply bite-sized bits of the previous large, interdisciplinary lecture. The historical lecture content was split into small 25-minute sections so that students from different degrees did not have to sit through "how the other guys do it." Several module days were added to the calendar so that students could choose two out of six modules to attend on that given day. In order to test the approach, students were required to prove attendance via i>Clicker® quizzes before and after the module.

The module concept was first tested on the "off semester" students starting in Spring 2014. The group was composed of 55 students with all four majors represented. At the end of the semester, 25% of the students in the class reported going to more modules than required. Less than 5% of the students reported that they had attended a module "just for the attendance credit."

Moreover, student evaluations of the course improved significantly over previous semesters. Responding to the prompt "The teaching methods used in this course are effective for promoting student learning," students responded with an average of 4.4 on a 5.0 scale. This compares to a 2.9 on a 5.0 scale the semester before implementation. It is important to note that the university changed from paper to electronic course evaluations between the two semesters so the response rate was much lower for the semester of implementation. However, course evaluations prior to the module implementation were consistently in the range of 2.5 to 3.2 and since implementation have been consistently above 4.0, leading to the conclusion that the change has made a significant, positive impact on student perceptions. Student comments like "The modules are very helpful in defining what is expected of us" further reinforce this conclusion.

Since the trial semester, the module approach has developed rapidly to better support students. Because students are required to either click in via i>Clicker® or complete a post-module quiz online to prove attendance, valuable instructional data is made available to the course faculty. Attendance results make it possible to quickly distinguish between topics that draw students and those that do not. In addition, students have begun requesting specific topics be added that would better support them in their projects. Due to student requests, and resource limitations, modules that are well established are now being transitioned to online resources while in-person modules are used to develop new topics.

Table 2 - Sample of Modules Offered

Title	**Overview**
Outline Construction Specs	In the construction industry, outline specifications are a common mechanism to communicate the design quality and requirements in the early phases of design. This module contains a discussion of the standardized organizational structure and course requirements for outline specifications.
Product Requirements	Product requirements are succinct, detailed statements of the limits and metrics for success placed on a design project. This module will discuss how to write a good set of requirements so that the team clearly understands the end goal of the project and knows how to prove compliance with the requirements.
Code Analysis	Engineers must design within the constraints of building codes that are adopted and enforced by governmental entities to protect public safety and health. This module contains an overview of common codes and regulations that may affect your Senior Design project.
Introduction to Standards	Engineers often must design within constraints set by 3^{rd} parties. This module introduces common standards bodies and certification agencies that you may need to interface with to complete your project.

Currently students are presented with sixteen module options and are required to complete eight modules of their choosing. Of the sixteen modules, six are available online and the rest are presented in-person by course faculty on designated module days. Students prove completion of modules by completing a post-assessment quiz, which is either embedded in the online video or available on the class Blackboard site (for in-person modules). Examples of four modules that cover closely related topics are given in Table 2. For example, for a construction project, Outline Construction Specifications and Code Analysis are likely great fits to assist a student, while the Product Requirements and Introduction to Standards modules might not apply. In contrast, for a project working with electrical power, such as a car charging station, the Introduction to Standards and Code Analysis modules might apply. Offering this flexibility to the student is a major goal of the module system and directly addresses departmental concerns about delivering targeted content as part of the multidisciplinary course.

Future Work

At this time, anecdotal evidence has been collected via student evaluations that the two initiatives described are effective. Going forward, funding has been provided by the CSM Center for Teaching and Learning to expand and refine the modules in the Capstone program. As part of this effort, more quantitative module effectiveness assessments will be developed. The implementation of a common language for design assessment is currently being studied in a 4-year longitudinal study of students from cornerstone to Capstone with results expected in two years.

Conclusion

Experience working on multidisciplinary projects is a key component of the education of students at CSM, but making multidisciplinary programs work requires a delicate balancing act. Working with key stakeholders in the departments served by the Capstone design program to develop a common design assessment language has greatly aided buy-in by both students and faculty. However, it is important to allow students to embrace their degree specific tools and terminology. To this end, a modular approach to teaching has been developed that has greatly increased student engagement and satisfaction with the multidisciplinary program.

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