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Self-Guided Professional Development as an Enabler for Multidisciplinary Programs

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Work in Progress: Self-Guided Professional Development as an Enabler for Multidisciplinary Programs

Abstract

The capstone design program at Colorado School of Mines serves three departments and four degree programs, each having their own demands, distinctive industry-specific languages, and departmental expectations. Each discipline is looking to the capstone design program to provide ABET required capstone projects and assessment, professional practice training, and instruction in multiple discipline specific design tools and techniques to their students. This paper describes the use of student-specific professional development plans, in combination with a menu of online content modules, in order to embrace the unique needs of each discipline while enabling multidisciplinary collaboration in a single course. While this is an early effort to assess the modules, initial surveys suggest that students and faculty value the modules' content and feel that overall the quality and length of module production is good. Future work will assess the utility and application of the modules to their design projects.

Keywords

Self-guided Learning, Modular, Multidisciplinary

Introduction

Despite a long history of multidisciplinary collaboration at Colorado School of Mines (CSM), maintaining a strong multidisciplinary capstone program has required innovation in pedagogy. The capstone design program at CSM serves three departments and four degree programs, each having their own educational demands, distinctive industry-specific languages, and departmental expectations. While there are several existing models to facilitate multidisciplinary capstone collaboration in existence, they do not fit the needs of a fully integrated capstone program like that at CSM. Project-by-project attempts at targeted multidisciplinary integration across separate capstone classes are challenging to scale for large programs. Tracked multidisciplinary programs like those found at RIT and Michigan Tech can be challenging to coordinate at the program level. Regardless of the approach, each discipline is looking to the capstone design program to provide ABET required capstone projects and assessment, professional practice training, and instruction in multiple discipline specific design tools and techniques to their students.

This paper describes use of student-specific professional development plans, in combination with a menu of online content modules, in order to embrace the unique needs of each discipline while enabling multidisciplinary collaboration in a single course.

Background

Colorado School of Mines has a long history of multidisciplinary undergraduate programs spread between the freshman and senior year. All freshman students at CSM are required to complete a one-semester, multidisciplinary cornerstone design course which was one of the first such courses in the country.[1] In addition, the Civil, Environmental, Electrical and Mechanical engineering degree programs have historically required their students to complete a coordinated Multidisciplinary Engineering Laboratory sequence.[2] Finally, multidisciplinary capstone courses have been experimented with at CSM since the early nineteen nineties.[3] Even with this strong foundation, there are significant challenges to running a successful, multidisciplinary capstone program.

Capstone programs differ from other multidisciplinary courses in several ways. Freshman experiences don't have the same expectations to deliver discipline specific technical content that are required at the senior level. For that reason, a closer parallel to multidisciplinary capstone might be found in multidisciplinary laboratory sequences. However, at CSM, these experiences have been explicitly designed to address the common, or overlapping, parts of the curriculum rather than addressing the differences.[2] Multidisciplinary capstone programs often attempt to use the idea of systems engineering to speak a single, common language between all disciplines.[3, 4] However, different industries and fields of study do have different tools, processes, and outputs and ignoring these can be problematic in a capstone setting.[5]

Two common models for multidisciplinary capstone design programs can be described as parallel but separate and tracked. One common approach for multidisciplinary capstone collaboration is simply for capstone course instructors in two different departments to agree to create a hybrid team of students to address a single project. Often times these parallel but separate collaborations require students from each major to complete separate course requirements and deliverables for each department while working on a single project. This approach has the strength of allowing each discipline to learn unique tools and create discipline relevant deliverables. However, the approach does not scale well. An alternative approach used by many large capstone programs is to arrange projects into tracks. The Multidisciplinary Senior Design (MSD) program at Rochester Institute of Technology (RIT) has created project tracks around multidisciplinary topics. The tracks have aided in aligning the program projects with departmental objectives while avoiding strict departmental divisions. This has been done to tie projects to faculty areas of interest, thus grouping these tracks around unique sets of technical tools, processes and techniques. RIT actively manages the Design Project Management course that is required for all project managers in the program so that it provides a common basis for all tracks and their projects.[6] Michigan Tech's Enterprise Program follows a similar logic. While the Enterprise Program is more than just capstone, students can gain capstone credit in many engineering programs at Michigan Tech after completing four-semesters of enterprise activity. Each Enterprise is a studio arranged around a key area (e.g. Wireless Communication Enterprise) lead by a primary advisor with expertise in that domain.[7]

In all these examples of multidisciplinary capstone, programs are striving for some type of differentiated instruction. Differentiated instruction is an active process where instructors attempt to provide different students with different learning options. These techniques are well established and have been used in K-12 education extensively.[8] Choice or menu activities are one example of a type of differentiated instruction which involves providing students multiple possible paths to completing a given assignment. The literature is lacking explicit examples of differentiated instruction in college-level engineering design courses. However, higher education examples that are published in other areas support its use.[9]

Use of out-of-class videos to deliver course content so that in-class time can be used on active learning has been widely studied at the college level in hybrid or flipped classroom settings. In upper level classes, even those involving open-ended design problems, research shows equivalent or improved learning outcomes when using a flipped classroom approach.[10] Tying together the concepts of differentiated learn with out-of-class videos to deliver content might provide a unique way to support multidisciplinary collaboration on capstone projects.

Course Design

The Capstone program at Colorado School of Mines serves three departments, four degree programs, in the College of Engineering and Computational Sciences. The two-semester course is coordinated at the college level and is the required capstone experience for all Civil, Electrical, Environmental and Mechanical Engineering majors in the university. In addition, a small number of students from other majors enter the program each semester to take part in specific projects to meet either technical elective or capstone requirements in their chosen degree program. Each of the three departments involved in the capstone program is looking for students to walk away from the program with

1. a significant capstone project experience,
2. professional practice and ethics training, and
3. knowledge of discipline specific design tools and techniques.

A leadership committee, supported by faculty advisors, oversee the Capstone program to ensure these key requirements are being met. The leadership committee is composed of one representative from each department and is charged with approving projects, developing the course content, and supporting faculty advisors. Faculty advisors in the program oversee two to four teams depending on appointment (approximately 12 to 24 students) and grade and advise those students. Approximately seventy-percent of the faculty advisors are adjunct faculty with greater than two-years of industry experience in their field of expertise.

The two-semester course sequence serves roughly four-hundred students each semester, which equates to approximately sixty, unique projects. Projects are started on both fall/spring and spring/fall rotations to accommodate student graduation schedules. Average team size for the program is six students, however teams are built to fit the challenge, so they can vary from as many as fourteen students to as few as four. Projects range from design of custom electro-mechanical products to design of remediation plans for old mine sites in the area.

Providing a significant capstone project experience is the easiest departmental expectation to meet. Multidisciplinary capstone design experiences have been shown to provide rich learning environments.[11] Careful selection and scoping of projects goes a long way towards providing a positive project experience. At CSM there is a defined project approval process where potential projects are vetted by a panel of faculty with one representative from each participating department. Projects with a need for cross-disciplinary collaboration are given preference in this process. Teaming must also be carefully considered so that multidisciplinary teams can succeed and efforts are ongoing at CSM to find the best means of creating high-functioning multidisciplinary teams.[5] Currently, teams are not required to have a representative from each major. Instead, project teams are built by combining students from disciplines that can make meaningful contributions to the project.

Professional practice content, such as project management, and ethics training are generally topics that can be taught in such a way that they are common and transferable between degrees. At CSM, the first three weeks of the semester are considered "new employee training" and all students, regardless of major, are required to complete a number of in-class activities and out-of-class assignments focused on the topics of team management, communication, project management, ethics, and liability.

Providing appropriate, discipline specific technical content to all students in the multidisciplinary program is a challenge. For the purpose of this paper, discipline specific content is considered the things you do to tie analysis-based classes in each major to open ended problem solving activities. To illustrate the breadth of required technical content expected of the current course, Table 1 describes key tools required for each major phase of three recent, representative projects.

The biologically-active filtration design challenge team was composed of environmental and mechanical engineering majors. The team designed, built and tested a lab scale biologically-active filtration system for decontamination of produce water from fracking operations. To succeed, the team needed to perform a successful literature review, quickly test multiple theories at a bench scale for feasibility and then use a variety of software to design both a lab-scale test apparatus and predict the expected performance of the system. The final output of the project was a working experimental system with results ready to be published in an academic journal. Contrast that with the parking lot design challenge team which worked with the local city to survey a potential site and design a multi story concrete parking structure that complied with local building ordinances. Rather than an academic literature review, the team of civil and environmental engineering students, needed to understand building codes. Rather than bench-top testing, the team needed knowledge of construction best practices and how to estimate construction costs. Moreover, the software necessary for a construction project is different and the final results must be provided to the client in industry standard drawings rather than being packaged for publication in an academic setting. As a final example, consider a team working on the Society of Petroleum Engineers Drillbotics competition. These mechanical and electrical engineering students designed a robotic system to drill through rocks of unknown composition. To accomplish this they had to seek out industry experts in drilling and understand the required functionality and behavior of the system using classical systems engineering techniques. Their final deliverable was a working prototype with verification results showing that it met particular requirements. In all cases, these projects provided great multidisciplinary challenges for the students. However, it is hard to design course content around this breadth of projects.

Table 1 - Discipline specific tools for example projects

Project Title	**Biologically-active Filtration Design Challenge**	**Parking Lot Design Challenge**	**Society of Petroleum Engineers Drillbotics Competition Team**
Majors Involved	Environmental/Mechanical	Civil/Environmental	Electrical/Mechanical
Key Early Design Activities	❏ Research of Academic Literature ❏ Lab Scale Testing	❏ Building Codes and Ordinance Review ❏ Site Analysis	❏ Expert Interviews ❏ Functional Modeling of System Behavior
Key Design Activities	❏ Reaction Modeling (multiple software tools) ❏ SolidWorks CAD ❏ LabVIEW Software	❏ AutoDesk CAD Tools ❏ Construction Feasibility Analysis Construction Cost Estimation	❏ SolidWorks CAD ❏ LabVIEW Software ❏ Systems Testing & Integration Planning
Key Final Outputs	❏ Working Experimental Rig ❏ Experimental Results Proving Efficacy	❏ Technical Construction Drawing Package ❏ Design Specs	❏ Technical Drawing Package ❏ Working Prototype ❏ Verification Test Results

To address the diverse content required to support students in the program, a unique differentiated learning approach was developed. The course faculty developed a series of online video modules on topics ranging from building codes to prototyping. A list of the currently available modules is provided in Table 2. Each student in the capstone design program is expected to develop and submit a personal, professional development plan for the two-semester course sequence. The professional development plan requires students to select eight modules from a list of available topics that they will complete throughout the course of their capstone experience.

Modules (posted to the learning management system (LMS)) are 10-20 minute videos, with embedded quiz questions. The majority of the modules were created as a voice-over graphics presentation using Camtasia 9 by the course faculty. However, some of the videos included recorded presentations by guest speakers in front of a green screen. These more complex modules were recorded with assistance from the Trefny Innovative Instruction Center at Colorado School of Mines. All modules used Camtasia's interactive quizzing functionality to prompt student interaction with the module every three to five minutes. The interactive modules were then imported into the institution's LMS as a SCORM package. This allowed grades to be automatically entered into the course gradebook when students completed a module. The majority of the modules require a score greater than 60% on the embedded quizzes for a grade to be counted. Students can retake the modules as many times as they would like. Completion of the professional development plan and modules is worth just over ten-percent of the course grade for each student. This approach allows divergence in student expertise and learning opportunities over the course of their two-semester project.

Table 2 - Currently available modules

Module Title	**Module Description**
RACI	Guides students on how to use roles and responsibilities table to clarify project expectations.
Needs to Requirements	A guide for how to use Quality Function Deployment to turn vague customer needs into a list of engineering metrics.
Product Requirements	Assists students in writing effective product requirements statements and grouping them into a logical requirements document.
Code Analysis	Provides an introduction to International Building Codes and sets expectations for code compliance in the capstone program.
Site Analysis	A step-by-step guide to analyzing a possible building site before generating possible solutions.
Outline Construction Specs	Explains the complementary nature of drawings and specifications for a construction project and introduces MasterSpec.
Boundaries and Behaviors I	Introduces abstraction and use of black box models as tools to better understand projects.
Boundaries and Behaviors II	Guides students through use of functional modeling to abstract and explore electro-mechanical design challenges.
Embodiment Design	Defines embodiment design and introduces several graphic tools that assist in embodiment design.
Product Development Process	Explains the product development process and provides suggestions for refining a product development process.
Prototyping	Introduces the “typical” prototyping steps taken to develop a design and provides examples of each step.
Hazard Analysis	Demonstrates the process of completing a hazard analysis for a sample project
Technical Construction Drawings	Illustrates an iterative approach to designing a clear and concise set of construction drawings.
Extension Module	Faculty can give each student one module credit for completing a software tutorial or other extension activity and providing proof of completion.

A forerunner to this approach to self-guided, differentiated learning in a multidisciplinary environment was first tested in the spring of 2014 with a series of in person micro-lectures and has been refined and improved since. Initial student feedback was extremely positive with over 25% of students reporting completion of more modules than required and less than 5% of students reporting that they completed a module “just for credit”. In addition, while no causal comparison can be inferred, the introduction of module-based education has been correlated with strong improvements in student evaluations of the course.[12]

Research Method

Sample

Instructors from the course surveyed and assessed the students and faculty advisors in the fall 2016 and spring 2017 Senior Design I course offerings. The response rate for fall 2016 included 23 students out of 314 (7% response rate) providing 47 reviews and 12 out of 16 faculty (75% response rate) advisors providing 17 reviews. The faculty advisors polled included eleven adjunct and five full-time faculty with backgrounds ranging from civil, structural engineers, to water engineers, to mechanical designers, and retired engineers.

Data Collection

The goals for this study stem from continuous improvement efforts to determine student participation with the modules, to discern student and faculty perceptions of module quality, and to develop guidelines for future improvements for this differentiated learning approach. To this end, four sources of data were used, (1) student completion data from the LMS, (2) student course evaluation feedback, and a custom survey on the course modules sent to (3) all students in the course and (4) faculty involved in the program.

Quantitative data was taken from two sources: (1) module completion statistics through the campus LMS, and (2) a distributed, anonymous survey. Respondents were asked to rate one or more modules on a Likert scale of 1-5, with 5 being the highest rating, on the following module criteria: content, value, quality of production and length. Qualitatively, respondents could also provide feedback specific to that module. Finally, respondents were asked if there were other modules or content area they would like to see in capstone.

Results

Overall, the review of the professional development modules were positive from both faculty and students. Program faculty were generally positive about the inclusion of differentiated learning modules. Of the sixteen faculty surveyed, thirteen responded to the survey and provided feedback on at least one module, nine provided feedback on more than one module (see Table 3). Average ratings were above 4.0 on a 5-point Likert scale. Faculty rated the two longest modules (20 minutes and 16 minutes respectively) lower than others overall, and, with one exception, recommended modules not go longer than approximately 10 minutes. Faculty provided suggestions for minor improvements and some terminology updates to the modules to better align with their expectations. Examples of faculty feedback are provided in Table 4. Since our program faculty are primarily adjuncts with industry experience, this input is extremely valuable.

Table 3 - Survey responses from faculty and students on four criteria for evaluating the modules. Ratings were conducted on a Likert scale from 1-5, with 5 being the highest rating

	Student Reviews (N=47)		**Faculty Advisor Reviews (N=17)**	
Rating Criteria	**Mean**	**SD**	**Mean**	**SD**
Content	4.2	0.77	4.4	0.62
Value	4.0	1.07	4.5	0.51
Quality of Production	4.2	0.93	4.3	0.85
Length	3.9	0.95	4.4	1.06

Students criteria ratings were slightly lower than the faculty (see Table 3). Since students were required to watch at least eight modules, they had more opportunity to compare across modules and thus would likely rate one higher or lower than another. Examples of student feedback are provided in Table 4. When students were asked about additional content 33% of those that responded requested professional communication skills, especially with clients. Others suggested content including entrepreneurship, systems engineering and additional modules in electrical and environmental engineering.

Discussion

One best practice in crafting differentiated learning activities is to make sure all possible paths are acceptable paths for the student. The module implementation gave students a large amount of freedom in their education, and students made mixed use of that freedom. When looking at civil, mechanical and electrical engineering student module choices, they were relatively logical as a group. Table 5 lists the most popular modules for each major based on number of completions. Interestingly, the completion data shows that environmental engineering students took unexpected mixes of modules; environmentals favored modules on Quality Function Deployment and electro-mechanical embodiment design over modules like Site Analysis. This unexpected result may be tied to a lack of proper environmental engineering content based on student feedback on course evaluations. In addition, faculty observed many students waiting until the last minute to complete the professional development modules rather than being proactive which implies that more structure and guidance as well as a timeline for completion may be necessary in future course offerings.

Table 4 - Open-ended survey responses from faculty and students evaluating the modules.

Positive Feedback	
Student	● "This module was well put together, it did seem to have a focus on mechanical engineering ...but for some other departments, maybe 10-30 seconds could be used to give similar examples in different fields …" [**Prototyping**] ● "One of the more useful [modules]. Made a concept simple and easy to understand." [**RACI**]
Faculty Advisors	● "I appreciated the breadth of content presented ...The module was very clear and concise, you might emphasize the need for...some engineering work required and basic calculations in parallel with simulations and modelling." [**Prototyping**] ● "Very informative, I think it's a good module with enough detail to be helpful." [**Outline Construction Specs**] ● "It is important for the team create a RACI matrix, because they know how wish to proceed their project and what the client should do." [**RACI**]
Instructors' Take-away for Continuous Improvement	
● Most modules that maintained timing under 10 min. received more positive ratings and constructive feedback for improvement. Conciseness helps in delivery of material	
Critical Feedback	
Student	● "The content could be a little bit less repetitive and could be made more concise. The excess repetition devalued this module." [**Boundaries & Behaviors,** 00:20:14] ● "I didn't learn anything new from this module. It was repetitive and simple things I think most students already know" [Prototyping] ● "Not good waste of time" [**Prototyping**]
Faculty Advisors	● "It's probably longer than it should be -- videos should be 5-10 minutes max before people stop paying attention... [Instructors] cadence is slower than what is best for a video, especially a screen capture …" . [**Boundaries & Behaviors,** 00:20:14] ● "Too much content for one module, more examples would be helpful" [**Product Development Process**] ● "I think that a mechanical or civil example (or more detail on those elements) in conjunction with the electrical emphasis would have helped." [**Embodiment Design**]
Instructors' Take-away for Continuous Improvement	
● Length of modules was the most critical feedback. Prioritize all recordings to be under 10 mins. Also watch pace and tone of voice - voice should be as dynamic as it is in the classroom. ● Either include examples that cover all disciplines, or if too long, consider modules that are discipline specific on certain design topics. ● Remind student at start of modules that hey may have seen content before, but this is a reinforcement of material.	

Students seemed to enjoy the module options and many went beyond the professional development requirement of eight modules. Two-hundred fifty-three of three-hundred nineteen (79%) received perfect professional development module scores in the class meaning that they completed required number of modules and redid them until they got a perfect score. This number was much higher than expected. Multiple students mentioned the modules as a positive part of the course in course evaluation comments, particularly the freedom to choose. Moreover, seventy of the students (or 22%) completed more modules than actually required by the class.

Table 5 - Fall 2016 cohort most popular module topics by major

Module Title	Students from Major	Module Description (number of students from major completing module)		
Civil Engineering	36	Technical Construction Drawings (36)	Site Analysis (33)	Outline Construction Specs (32)
Electrical Engineering	63	Needs to Requirements / Embodiment Design (tied for 1st with 58)		Prototyping (54)
Environmental Engineering	20	Needs to Requirements (18)	Embodiment Design (17)	Site Analysis (16)
Mechanical Engineering	192	Prototyping (176)	Embodiment Design (168)	Needs to Requirements (162)
Other Majors	8	Embodiment Design / RACI / Prototyping (tied for 1st with 8 each)		

The feedback from both faculty and students was the most valuable survey outcome in this early stage of module development. To provide additional and broader content across all disciplines, we are recruiting additional faculty and clients to help develop design and project management related content. Based on faculty advisor feedback, modules on technical drawings, costing, budgeting and scheduling will be added, though they may be supplemented by changes to lecture content, especially skills that are of value across disciplines The course faculty create the the majority of the modules, and with two new faculty joining the capstone instructors this year, we anticipate to increase the number of modules by at least 50%. Additionally, length of modules will be held to 10 minutes or less. The Trefny Innovative Instruction Center will continue to assist with video editing and incorporating online quizzes real-time in the videos. Course assessment and evaluation will accompany these changes and additions to the course.

Limitations

There are several limitations to this current work. The student response is not significant at this point, though we anticipate increased feedback in the spring semester when the survey correlates with completion of the professional development modules vs. the end of the semester. While the criteria for evaluating the modules is important to capture to determine if the modules are an effective mode of providing topical design content, we have not evaluated the direct application of the content by the students. This is the next step in the course development and addressed below.

Conclusion

Addressing the challenges and highlighting the application of a differentiated education approach in a multidisciplinary capstone design course was the intent of of this initial work. While the design approach is discipline and project specific, online modules developed by faculty and engineering professionals provide an opportunity for students to gain design instruction they need to advance their project with advanced design tools and concepts. Overall, both students and faculty were happy with the format of the design content, and more modules will be launched in the coming academic year. Program administrators are happy to have the discipline specific content while having their students participate on multidisciplinary teams. We will continue to evaluate both the utility and the application of the module content in the coming years.

Future Work

More important to students watching the video is the application of the content. Future assessment will query students at the end of the video to ascertain if students feel they will use the tools/methods presented in the module in their project. Course assessment, as well as an end-of-semester survey, will assess if they did apply the content and how. With continuous improvement efforts, modules will be added to this course to expand design and professional skills content and to address requests from our students and faculty advisors. Our work-in-progress entails integrating these (and future) modules in other courses. Broader dissemination of the modules throughout the curriculum helps thread design content into other courses. Those opportunities are being explored with the assistance of the Undergraduate Curriculum Committee in their effort to adopt a Teaching Across the Curriculum model for specific engineering skill sets, including design.

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