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Multidisciplinary Construction Engineering Design Projects

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While the design process and design tools are described differently in different engineering disciplines, there is a core science of design. This shared core of design can form the basis for interesting, successful and engaging real world design projects in a multidisciplinary design program. At the Colorado School of Mines (CSM), a successful model for such a program exists, bringing together students from Civil, Environmental, Electrical and Mechanical Engineering to develop design solutions to complex problems faced by real world entities. This paper discusses the differences in design perspective between the disciplines and how these differences, both real and sometimes imagined, can be bridged by understanding how they arise from a common engineering core of design. As examples, we will draw upon a set of construction engineering design projects that engaged the breadth of our student population. Furthermore, we will describe the model for the program we have developed, the metrics by which it has been an assessed and how those assessments were received during our recent Accreditation Board of Engineering and Technology (ABET) visit in 2013. The purpose of this paper is to stimulate discussion in multidisciplinary engineering and design collaborations and to demonstrate that these projects sample substantial real world design challenges.

1.0 Introduction

CSM is fortunate to have a multidisciplinary Engineering Design Program (EDP). In many institutions, such a program is desirable, but historical precedents and disciplinary biases make implementations difficult. Yet, in the professional world, multidisciplinary design teams are quite common, and the ability for recent graduates to be able to effectively contribute to multidisciplinary design teams is prized. ABET recognizes this professional reality through its student educational outcomes, often simply denoted as the a-k criteria.

This paper describes the program operating at CSM. While our curriculum is not appropriate for all institutions, we believe that there are insights to be gained from how this program operates that may provide inspiration to other institutions. In particular, the EDP at CSM plays a significant role in our ABET accreditation. Having recently been through an ABET visit, we also discuss our strategy and insights into demonstrating an effective multidisciplinary design program to ABET.

Critically, we present two case studies that highlight some of the advantages and challenges we have observed in our operations. These case studies also highlight that while design has a common core across disciplines, there are challenges due to differences in how disciplines and in particular sectors of the economy perceive design.

Finally, in the spirit of continuing improvement, we present several ongoing initiatives intended to further enhance and improve this multidisciplinary program. By the time of the conference, we will also be able to share our initial evaluations of the effectiveness of these initiatives.

2.0 Program and Course Overview

The EDP at CSM serves five degree programs. The EDP encompasses Senior Design for each degree program, but also includes a Graduate Design Program. For the purposes of this paper, our focus is primarily upon the undergraduate senior design curriculum. Students pursuing B.S. degrees in Civil, Electrical, Environmental and Mechanical Engineering are required to take the two semester course sequence in their senior year, usually during their final two semesters of study. In addition, students pursuing a B.S. in Engineering, with a specialty in one or more of the above areas, are also required to complete the course. These degree programs are housed within three different departments within the College of Engineering and Computational Science.

By mutual agreement and tradition, the senior design sequence has been a common course at CSM since its inception. The program is led by a Director, appointed by the Dean of the College. Each of the Departments has representation on a Senior Design Leadership (SDL) Committee, chaired by the Director, and all degree programs contribute to staff the course. Each course implementation is led by a small team of course faculty who coordinate the course according to a curriculum plan developed by the SDL Committee. Individual student design teams of 4-8 students are managed by Faculty Advisors who are coordinated by the Course Faculty. In addition, each design team is assigned one or more Technical Consultants from the school faculty to provide in depth technical guidance during their project. In addition, projects with a significant Human Centered Design element are also assigned a Social Context Consultant to assist the team in developing their project in concert with the sponsoring community. Each team is assigned to a client sponsored project. Project clients are extremely diverse, and include companies, on-campus organizations, governmental organizations, non-profit organizations, community organizations, and private individuals. A successful team will balance the needs of and utilize the skills from multiple distinct interests as shown in Figure 1.

Enrollment in the course is significant, and in recent years has been growing. The sequence is offered as a Fall-Spring (on-sequence) and a Spring-Fall (off-sequence) set of courses. The most recent on-sequence offering enrolled 273 students, while the off-sequence enrolled 83. This equates to approximately 60 projects in progress at any time.

The EDP is operated as a two semester course sequence worth a total of 6 semester credit hours. The first 8 weeks of the semester are used to introduce design methods and processes that the teams are expected to use in their projects throughout the remaining 22 weeks of the course. Design reviews are held at approximately 7, 13, and 20 weeks into the project. Many projects go beyond paper projects and involve some level of construction, fabrication and/or physical testing or proof-of-concept demonstrations.

Students are matched to projects based on a bid process. Students form teams of typically 2-3 students, and each team develops a bid on multiple projects, listed in preferential order. The bid asks the team to look at the project description and predict the tasks and skills necessary to successfully complete the project. Further, each team then must assess their own skill sets and explain why their skills are project essential, and thus why they should be assigned to the project. The actual design team is selected by the course faculty and faculty advisors from the bid assignment. Typically, the team that does the best job understanding the necessary project tasks and skills is first assigned to form half of the team. The other half of the team is selected to fill out the skill competencies necessary for the project. This balances student interests and preferences with the necessary skills for the project as defined by the sponsoring client.

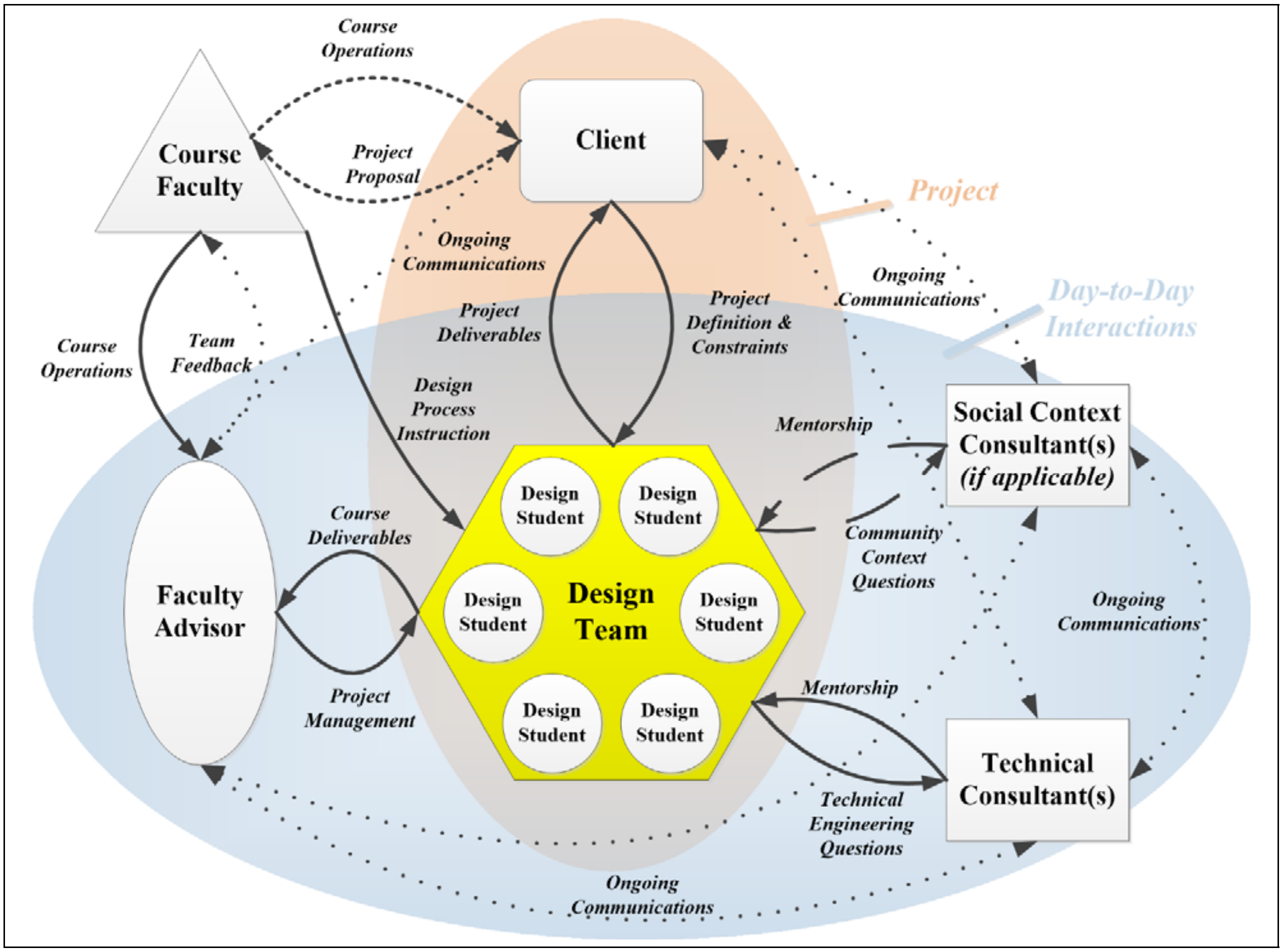

Figure 1: Organization of the EDP from the perspective of a Design Team.

Once students are assigned to project teams, the projects are matched with Faculty Advisors. While it is desirable to match the project with the technical experiences of the Faculty Advisors, in practice this is not always possible given that Faculty Advisors are assigned to the course before the enrollment of the class is fully known, nor is the design project portfolio fully defined. Thus, each team is also assigned one or more Technical and/or Social Context Consultants from the school faculty to provide technical guidance with respect to the project, as well as to facilitate access to school resources and facilities that the team may need to use for their project.

All five degree programs use senior design as part of their ABET assessments. However, how the EDP program is used varies between degree programs. These assessments are summarized in Table 1. Passage was somewhat arbitrarily determined to be 80% of the students achieving a professional practice standard.

Table 1: ABET Student Outcomes Criteria as assessed through the EDP by degree program.

ABET Criteria	**BSCE**	**BSEE**	**BSEnvE**	**BSME**	**BSE**
(a) an ability to apply knowledge of mathematics, science, and engineering					X
(b) an ability to design and conduct experiments, as well as to analyze and interpret data					
(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability	X		X	X	X
(d) an ability to function on multidisciplinary teams	X	X	X	X	X
(e) an ability to identify, formulate, and solve engineering problems					
(f) an understanding of professional and ethical responsibility	X	X	X	X	X
(g) an ability to communicate effectively	X	X	X	X	X
(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context	X	X	X	X	X
(i) a recognition of the need for, and an ability to engage in life-long learning	X	X	X	X	X
(j) a knowledge of contemporary issues	X	X	X	X	X
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.					X

3.0 Case Studies of Multidisciplinary Construction Projects

For illustration, two recent projects were selected as case studies. The two selected case studies demonstrate similarities and differences in design perspectives from the four participating engineering specialties on construction projects. Both case studies were completed by students in the Fall 2012 – Spring 2013 course cycle.

3.1 Case Study #1 – Design of a Zip Line With An Innovative Automatic Braking System

Description

In this case study, the project involved the design of a unique zip line on the client's private property. The project scope included engineering calculations and construction drawings, but excluded the construction itself. The zip line was later constructed by others based on the team's design.

A zip line is an outdoor recreational apparatus that generally consists of a take-off platform at a high elevation, a landing platform at a low elevation, and a cable that connects the platforms. A rider uses the zip line by connecting their harness to a trolley that is connected to the cable. The rider generally jumps off of the take-off platform, and traverses the length of the cable without any outside propulsion or power: the velocity is simply based on the initial acceleration, friction and drag, and the rider's mass.

A key component of the design of a zip line is the braking system used to bring the rider to a safe stop on the landing platform. A variety of braking systems have been used for this purpose. The simplest braking system requires the rider to generate friction with their gloved hand on the cable and decelerate. Other zip lines rely on the elevation differential between the take-off and landing platforms in order to bring the rider to a safe stop.

For this project, the client required that the students design an automatic braking system that would require no action by the rider for stopping, and that the system would reset for the next rider automatically. This requirement was considered to be the most challenging engineering component of the project.

The student team was comprised of 4 Mechanical Engineering majors, 1 Civil Engineering major, and 1 Environmental Engineering major. The final design of the braking system featured a braking pole connected to a braking block on the zip line via a cable. The rider's trolley impacted the braking block, which continued down the cable in tandem with the trolley. The braking block was connected to ballast in the form of coiled steel chain-link. As the rider continues down the zip line, ballast mass is gradually added to the system, ultimately enabling a controlled and safe stop.

Points of Interest with respect to Case Study #1

The multi-disciplinary nature of the project was successful in some ways, and problematic in others. One successful aspect of the project was that the students and faculty gained an appreciation of the nuances between design approaches between similar engineering disciplines. The majority of the students' engineering design effort was expended on the design of the braking system, led by the four Mechanical Engineering students. Equally crucial to the project's success, however, was the design of the supporting structures and the foundation system. The one Civil Engineering student was overwhelmed by the required structural and geotechnical work. Despite good intentions, the other students on the team were not able to provide much assistance with the structural and geotechnical design tasks, as they were unexposed to those fields. Specifically, some of the Mechanical Engineering students tried to apply first principles of solid mechanics to steel connections. For example, they created a finite element model for stress analysis in a bolt, being unaware that the design of steel connections is highly codified in the Manual of Steel Construction. They were also unaware that contemporary steel design for steel and members is based on the full stress-strain behavior of steel: specifically, the use of the ultimate stress in tandem with the yield stress in order to design connections.

In hindsight, it’s apparent that a team of 50% Mechanical and 50% Civil majors would have been more balanced for this particular design problem. The Environmental Engineering major did not have the knowledge base to contribute to the technical aspects of the project and was not well-utilized. The steel design work completed by the Mechanical Engineering students, although well-intentioned, often had to be re-done or discarded. The extra time expended on re-work prevented the team from completing certain critical aspects of the design, such as some of the connection details.

A second point of interest that manifested in this case study was the treatment of liability for the students, the faculty, and the University. Prior to this project, there were no formal liability waivers required for construction projects in the course. At first glance, the project appeared to be relatively simple and straightforward, but as the design developed, the students struggled with defining constraints in their design relative to the uncertainty of potential users of the zip line. Although the design was intended to be specific to the client’s height, weight, and build, what other users merited consideration? The mass and height of the rider are critical variables to consider in the system’s design. Additional mass results in additional acceleration and additional braking requirements. Minimal mass, such as the mass of a child, may result in excessive deceleration, as well as the potential for the child to be stopped short of the landing platform. Shorter users and children would have difficulty connecting their harness to a trolley that was proportioned for an average-height user and might try to climb to the zip line on miscellaneous objects or be hoisted by peers. Unsupervised children might also attempt to ride the zip line upside-down or in another configuration that could potentially excessively accelerate their head relative to their body.

The team did implement certain safety features to address these concerns. As they were most concerned about unsupervised children using the zip line structure without the owner’s knowledge, they designed the take-off structure with a collapsible mechanism that would impede (but not prevent) unauthorized use.

The project has drawn the course faculty’s attention to a more rigorous method to protect liability. With assistance from the University counsel, a simple liability contract that must be signed by the client, team, and University representative is now in effect for the course sequence. In essence, the contract states that the designs are prepared by students and not by Professional Engineers. The owner agrees that if he/she wishes to construct the student’s design, he/she must independently engage a Professional Engineer to review the students’ work, modify the design as necessary, and sign / seal for the project.

3.2 Case Study #2 – Design of A Combined Micro-Hydroelectric Power Generation System and Emergency Fire Hydrant System

Description

In this case study, the project involved the design of two systems for a small residential community: a micro-hydroelectric (or micro-hydro) power generation system used for revenue, in which the generated electricity is transferred to the grid and sold to the power company; and an emergency fire hydrant system to help protect the community from forest fires. The community is located in a relatively remote mountainous area, with no existing fire suppression system. The site straddles a fresh water creek that is a suitable resource for both systems. The student team was responsible for engineering calculations and construction drawings, but the scope excluded the construction itself; the project has not yet been constructed.

Hydroelectric power generation is suited for a massive scale, utilizing water sources that have the potential for high flow at a significant initial elevation (creating a high pressure head). Micro-hydro is the application of hydroelectric power generation to systems with smaller water flows that begin at high elevations. Typical micro-hydro systems concentrate slow water streams into a separate pipe (known as a penstock). Upstream, the design requires a dam and reservoir of water to add pressure to the penstock or a pump that causes high velocity flow. Downstream, the high velocity water exits the penstock into a turbine (a waterwheel), which is connected to a generator. The water is returned to the creek over riprap (large rocks) in order to reduce the velocity and protect the soil from erosion, so that the natural creek flow is only disturbed for the length of the penstock.

The desired emergency fire hydrant system would consist of a network of above-grade hydrants that are placed to cover the desired area with standard 1000-foot-long fire hoses, easily accessible from fire trucks on paved roads, and pressurized to ensure a minimum flow when in use. Unlike urban applications where pressurized water is provided via the city network, this rural fire hydrant system relies solely on creek water. Another key component to the emergency fire hydrant system is the design of the control system for the gate valves that direct the flow of creek water to a given hydrant.

The design of either the micro-hydro system or the emergency hydrant network in isolation is a relatively straight-forward exercise for college seniors. The complexity of this project was to design a solution that served both purposes via the same reservoir and penstock.

The student team was comprised of 3 Civil Engineering majors, 2 Mechanical Engineering majors, and 1 Electrical Engineering major. At the onset of the project, the skillset of the team seemed balanced and appropriate for the required design approach. The Civil Engineering students led the site analysis and overall layout of the components, and produced construction drawings for the upstream reservoir, hydrants, pipes, turbine, generator, and connections. The Mechanical Engineering students led the calculation effort to characterize flow and pressure within the system. The Electrical Engineering student was responsible for selecting an appropriate turbine for the application, researching requirements for the electrical connection to the grid, and designing the controls for the gate valve system.

Points of Interest with respect to Case Study #2

When initially recruiting and scoping this project, the Course Faculty recognized the need for Civil, Mechanical, and Electrical expertise. The Technical Consultant assigned to the project was an Environmental Engineer, who unexpectedly brought unique and crucial insight to the project that was unlikely to have been incorporated, should the Technical Consultant were to have been a specialist in another discipline.

The Technical Consultant led the team to consider the types of wildlife that rely on the creek, and how that wildlife would be impacted by the project's implementation. The redirection of a portion of the creek flow imposed a number of detrimental impacts to wildlife living in the stream. The students began to research the effects of increased temperature in the summer (due to reduced flow), and dissolved oxygen levels (due to turbulence) – both of which affect the habitat of the fish species that live in the creek. The team modified the design to include instrumentation to monitor water level and flow, and automated a valve closure to ensure safe conditions for wildlife. They also modified the design of the penstock's filter system to prevent small animals from inadvertently entering the penstock system. If a Technical Consultant from another department had been assigned to the project, these factors would probably not have been incorporated in the team's design.

Another point of interest in this project was the role of environmental regulations and legislation in the final design outcome. In particular, at the beginning of the project, the Mechanical Engineering students exhibited a tendency to neglect the site constraints, and focus on calculations that were not responsive to the actual site conditions present, such as the complexity of the topography. As the students continued to conduct research, they discovered that water rights legislation imposed significant constraints to the design, invalidating assumptions on which the flow and pressure design was based. While the Civil Engineering majors seemed to be better exposed to the effect of site-driven and legislative requirements on design due to their general curriculum, it served as a learning opportunity for the other students on the team. Additionally, all of the students struggled with putting the project in context socially. The hydrants had to go in physical places, on private property – and the students had to personally present the design variants to the community in order to get buy-in on the layout. Thus the project provided a valuable real-world experience in engaging the project's stakeholders that is not present in most engineering courses.

Finally, this case study also illustrates one shortcoming of the multidisciplinary approach within the constraints of an academic curriculum. The lone Electrical Engineering major on the team was not a very strong academic performer. Since there were no other Electrical Engineering specialists on the team, the final electrical design was not satisfactorily completed.

4.0 Where is the common core of Design?

At a high level, there are strong similarities in Design practices between disciplines. The process of understanding a design problem (i.e. gathering project goals, defining objectives and constraints, understanding the needs and interests of stakeholders), the need to consider multiple design solutions and select the "best" solution, and the need to produce a design product (i.e. to construct, fabricate, test and/or demonstrate the design) are common. However, the specific techniques used to achieve each of these high-level tasks varies between disciplines and projects, apparently as a function of the industrial sector of the project.

Notably, we have observed instances where cross-pollination of methods can be very effective. For instance, a primarily civil engineering project that emphasized rapid construction of prefabricated components found useful inspiration from a set of manufacturing methods that use color and shape to aid in reducing assembly time. In fact, many methods developed for the manufacturing sector may have significant applicability to pre-fabricated construction techniques.

Furthermore, cross-pollination works both ways. While manufacturing commonly uses a variety of decision methods to document the design through various calculations and tables, disciplines in the construction sector frequently engage in a narrative approach to assess the feasibility and applicability of systems (i.e. steel structure versus concrete structure, traditional HVAC system versus chilled beam system). Both approaches facilitate the communication of critical design decisions to team members and clients.

Cross-pollination is also seen in professional practice. Quality Functional Deployment (QFD) is a design technique widely used in manufacturing, but originated in the construction environment of a shipyard in the 1970s. However, based on discussions with currently practicing engineers in the construction field, QFD either never gained wide utilization within the construction sector, or has generally fallen out of use.

However, differences in terminology can also lead to misunderstandings. While some of these differences are superficial (i.e. clients versus customers, users versus stakeholders, or prototype versus model), others are more substantial. A manufacturing specification may document the criteria for component performance, while a construction specification documents the design characteristics that will achieve the required performance level. While similar, the use of the word “specification” does have subtly different meanings in different sectors. Worse yet, is where discipline specific terminology leads to confusion.

For instance, in manufacturing, reverse engineering is a common design activity, whereby an existing design is studied to gain an understanding of a prior design for the purposes of understanding competitor capabilities and strategies or to gain inspiration for a future design or as an initial step in revising a prior design for improvement. However, in construction, site and code constraints make this practice less common, although it can be argued that construction renovation projects must fully research and document the existing design before proposing changes to it. Nonetheless, terminology can become an obstacle in a multidisciplinary setting.

Another difference between sectors is in how design methods are applied. At a high level, construction projects tend to be very similar, i.e. in the design of a building, foundations, floors, walls and roofs are all present. However, at a detailed level, construction projects all essentially unique, owing to differences in local soil conditions and architectural design decisions that define the look and structure of a building. In a manufacturing setting, a toothbrush bears very little resemblance to an air conditioner at either a high level or a low level. Consequently, construction projects must rapidly move from concept to details, while a manufacturing project has to work through a wide variety of concepts in order to select the right concept to develop at a detailed level. As the time value of money is very significant in the construction sector, the design process is substantially accelerated in comparison to many manufacturing projects.

Documentation is yet another area that differs between the manufacturing and construction sectors. Construction documentation forms the basis of the contract to build the design and is evidence of compliance with all applicable codes and regulations. Thus documentation is of great significance as the primary deliverable of a construction design. In manufacturing, documentation is not less important, but the fabrication, testing and demonstration of a prototype of the design is of great significance and often occurs before the documentation is complete.

Legal issues present yet another difference. In construction, adherence to the code is the primary design constraint. In manufacturing, while codes may come into play in a design, many designs do not fall within the boundaries of any particular code. So while for some sectors, understanding and applying a set of codes immediately assists the design process, in other sectors, applicable codes must first be identified, and if any are found then they can be applied; otherwise the design must progress without guidance from a code.

The codified nature of construction limits the value of certain legal topics in the EDP. For instance, while intellectual property is a major issue in manufacturing, its significance in construction is far less. Similarly, non-compete and non-disclosure agreements are common in manufacturing, but seem to be far less common in the construction industry. However, an understanding of liability is much more significant for the construction sector than it is in the manufacturing sector, where individual engineers are much less likely to be solely responsible for approving a design. One need look no further than at the rates of licensure in particular sectors to confirm this assertion.

While the differences appear significant, a multidisciplinary design experience affords students the opportunity to encounter, understand, and appreciate why different sectors have developed distinct design processes. Occasionally, this experience may also lead to cross-pollination opportunities, where the best practices of one sector can spread to others.

5.0 Presenting this to ABET

Using data from the last five years of the operation of the program (in its current configuration), we were able to demonstrate that most of the assessment criteria were being met, and in the few cases where the criteria were not yet achieved, that substantial improvement had been occurring since the EDP was revised in 2009. This process of self-assessment also highlighted further areas for improvement.

At face value, it would seem that a multidisciplinary senior design program would be an easy sell to ABET as ABET outcome D requires “An ability to function on multidisciplinary teams.” However, this must also be balanced with ABET Criterion 5, which specifies “... one and one-half years of engineering topics, consisting of engineering sciences and engineering design appropriate to the student's field of study...” The final phrase, appropriate to the student’s field of study makes a multidisciplinary program a delicate sell to ABET. One must not only demonstrate that students of multiple specialties are collaborating effectively upon a project, but also that students are generally undertaking work in their field of study.

In the case studies discussed in Section 3, this is generally the case. For instance, in the zip line project discussed in Section 3.1, the brake design undertaken by the mechanical students is certainly a mechanical project and the steel design undertaken by the civil student was an appropriate civil engineering project. However, the mechanical engineers also attempted to assist with the steel design, and while they learned a considerable amount about the nuances of this area, they clearly did not have the appropriate background to effectively contribute. Finally, the team struggled to effectively utilize the environmental engineering student and focused the technical work in the areas well understood by the majority of the team.

In the second case study, we see some similar issues. While all of the students had important work to contribute that required design within their disciplinary specialties and specific disciplinary knowledge, the staffing mix of the team, and the capabilities of the individual students limited the ability of the team to complete the project to the level desired by the client. However, again the interaction of the disciplines produced numerous learning opportunities, and the multidisciplinary nature of the faculty advising and consulting with the team led to interesting educational experiences and insights.

Within the program, it was demonstrable that virtually all of the students involved in the program are able to undertake engineering design topics that are entirely appropriate to the student's field of study, although it is also clear that students may also become involved in design activities that go beyond their chosen field.

Based on these experiences, the lesson to be taken from the ABET assessment of this multidisciplinary program is that staffing of the projects, including both the students involved but also the faculty mentoring the students is crucial. A balance needs to be achieved between the skills and capabilities of individual students and the needs of the project. Improving this balance is a major focus of the program going forward.

6.0 Conclusions and Future Work

The nature of a multidisciplinary capstone course is significantly different than a capstone course limited to one discipline. Such a multidisciplinary course can provide meaningful interdisciplinary experiences for students and faculty, cross-pollination of design methods between sectors, and can robustly demonstrate compliance with ABET outcome D, "An ability to function on multidisciplinary teams."

Such a course also imposes significant challenges. This section contains a discussion of two ongoing initiatives to improve the course: the need to match suitable students and faculty to each project, and the need to provide pertinent and relevant content to the four participating majors.

Initiative 1- Improve team formation process to get the right expertise (faculty and student) on the team.

As illustrated in the case studies, the personnel selected to serve as Faculty Advisor and Technical Consultant, and especially their respective areas of expertise, can strongly influence the team's design focus and impact the final outcome of the project. The matching of the appropriate diversity of students (Mechanical, Electrical, Civil and Environmental) to the project is also critical to the project's success. Finally, the EDP can only meet the needs of each participating department if each student is afforded the opportunity to participate in aspects of engineering design pertinent to his/her chosen field.

Together, these factors combine into a set of complex management logistics for the Course Faculty. As described in Section 2, Faculty Advisors are assigned to projects by the Course Faculty; Technical and Social Context Consultants are assigned by Department Heads with recommendations from the Course Faculty, and students are assigned to projects by the Course Faculty via the bid assignment. Mismatches occur, to some extent due to the magnitude of the students and faculty participating in the course sequence.

We are piloting a modification to the EDP in Spring 2014 in order to improve the assignment of students and faculty to projects. In lieu of the bid assignment, we plan to match students to projects and to faculty in an environment that emulates a career fair. In advance of the matching event, each Faculty Advisor will research requirements for his/her projects and identify specific majors and/or skillsets that are required or desired. Students will also review the available projects prior to the matching event, and prepare resumes specialized to their top choices. Students interview for the projects with the Faculty Advisors, and the teams are assembled organically in three hours. Logistical support (whiteboards, Twitter, etc.) will be provided by the Course Faculty and a Teaching Assistant in order to dynamically broadcast team formation information, such as students already assigned to projects, as well as desired skillsets on projects that still require staffing. Although this process requires additional work for the Course Faculty, it is expected to improve the matching of students to projects, and therefore ultimately improve the final outcomes of the projects. The students will also gain an opportunity to practice several valuable professional skills, including resume preparation and interview practice.

We hope that this process will improve the staffing of projects, while allowing most students to choose their senior design project. We have found that teams of individuals working on a project that is of personal interest to themselves, produces teams with higher motivations to succeed.

Initiative 2- Diversify course content for probable career paths for a larger portion of the demographics.

As the EDP has developed over the past 5 years, the course faculty, a group with diverse academic and industrial experience, has engaged in a robust ongoing dialogue regarding the nature of engineering design, with a particular focus on similarities and differences between the disciplines. The ongoing dialogue has illuminated recognition of the intrinsic biases within the entire faculty that result from a lifetime of scholarship and experience within their own discipline. It is becoming apparent that some of the differences that were perceived to be between the disciplines are more strongly related to differences in industrial sectors. A review of published labor statistics from the U.S. Department of Labor (Bureau of Labor Statistics) proved to be particularly insightful as shown in Table 2.

Under the assumption that the demographics of our students' future career paths align with national trends, it is reasonable to expect that the design methods and approaches common in the Manufacturing Sector are most valid for the Mechanical and Electrical students. Indeed, these methods tend to resonate with those students and faculty, while having reduced applicability to Civil and Environmental students and faculty.

Table 2: Percentage of U.S. Workforce In Selected Industrial Sectors by Occupation[2]

	Industrial Sector		
Occupation	Manufacturing	Professional, Scientific, and Technical Services - Architectural, Engineering, and Related Services; Construction	Government
Mechanical Engineering	50.6%	22.9%	5.6%
Electrical Engineering	37.5%	24.6%	5.4%
Civil Engineering	1.0%	58.7%	28.1%
Environmental Engineering	5.8%	28.6%	26.7%

Conversely, the table also illustrates the high percentage of Civil and Environmental Engineers working in the Governmental Sector, compared to their Mechanical and Electrical counterparts. This data is linked to the prominent role of legislation and regulation for these disciplines, which leads to significant design constraints that must be addressed by engineers working in the Construction and Consulting Sectors. As documented in the micro-hydro case study, the Civil students were more responsive to legislative and regulative requirements than their Mechanical and Electrical teammates, due to their curriculum, internships, or a combination of the two.

Finally, it appears that of all of the types of engineering projects currently offered in the EDP, construction projects -- and the design methods and approaches that originate from that industrial sector – appear to be a very good match for an interdisciplinary course between the four participating majors. Construction projects have potential to provide opportunities for all students to work within their specialty area.

In the next evolution of EDP at CSM, we are challenged to balance both primary objectives of the course: to provide an opportunity for each student to work on a project that is meaningful to their discipline **and** future career track – while maintaining the advantages of seeing varied approaches to design via the existing multidisciplinary format.

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