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The Design Firm Model as Applied to Capstone Design

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As the culminating experience in an engineering program, capstone design provides students a glimpse into real-world design. Yet, real-world problems are complicated and dynamic. How, then, can we push the boundaries of successful capstone design programs to encapsulate an experience that more directly mimics the complexities and diversities that exist in professional practice? We propose a model for capstone design that more closely approximates professional engineering practice with students working on multiple projects, each on a distinct timeline and each with a different team of participants. The Human Centered Design Studio (HCDS) at the Colorado School of Mines has been refining a 'Job Shop Approach' to capstone in an environment dedicated to implementation of a design firm model with students working on multiple projects at different stages of development. A recent study of our student experience and overall course assessment provided opportunities for reflection on areas for continued growth.

Within HCDS, the dynamic nature of the design studio allows for project timelines that do not align neatly with the academic calendar. Students serve simultaneously on three different projects over the course of two semesters, providing a multi-project, multi-team, multi-client, and varied timeline learning experience. Similar to traditional capstone models, HCDS student teams work through the design process in its entirety, just not with a single project or in consecutive order. Instead, HCDS revolves around fluidity of team entry onto a project, where a new cohort takes over a project midstream. The studio model breaks down the design process into seven distinct steps, and every student completes each of these steps; however, the steps are typically distributed over multiple projects. Each step of the design process is linked to a specific course learning outcome, ensuring that the students meet all course requirements despite working on different projects at different stages of design development and in a non-consecutive order. This model has provided an educational experience more closely resembling an engineering design firm with varying project progression, timelines, and teammates. Capturing the learning outcomes associated with design-phase steps, instead of assuming all steps are completed as students work on a single project from start to finish, allows for a stronger focus on the *design process* as the central learning element, instead of the idiosyncrasies of any project or client, which become secondary concerns.

This paper presents the HCDS model for introducing and managing design project complexity in a team-based project course. The establishment of learning outcomes in association with steps in an educational design process creates a reliable and repeatable means for assessing students, but more importantly this reformulation greatly enhances the student experience. We provide an overview of our definition and implementation of our capstone design studio model with a focus on program structure and how it manifests in student requirements, deliverables and project management. This study also focuses on student experience as assessed via pre and post semester surveys. Exploration into model achievements and limitations are discussed. We also discuss the institutional forces that enable and constrain our innovative approach and explore how the HCDS model can be exported to other institutional contexts.

Introduction

Capstone Senior Design programs, the culminating educational experience for engineering students, draw on real-world, open-ended problem solving, professional development and the application of knowledge from undergraduate courses coupled with self-guided learning. As capstone faculty, let us explore a dynamic and immersive alternative experience through a design firm model. If requirements included student participation on multiple projects with multiple team members and multiple clients, can we craft an environment that mimics the workplace? We will present herein a different capstone experience that presents complexities in student progression while maintaining learning outcomes and ABET requirements.

As outlined in the most recent 2015 survey of ABET-accredited engineering programs, capstone design courses are often centered on an open-ended or loosely defined problem as presented by an academic or, more often preferred, an industrial client [1]. Students are required to develop a solution to the problem in the form of a product or process, participating on a team of nominally five students [2]. In some scenarios, the project teams are multidisciplinary, lending to an experience more representative of what the students are likely to encounter in the workforce. Design teams are often seen to mimic the structure of an engineering firm, whereby students assume roles such as *Project Manager*, *Chief Engineer, Communications Lead* and the like [3]. While the framework for providing student success through technical and professional development creates an alternative to more traditional lecture-based classes, there remain limitations in the capstone model's fit for professional practice.

One area of deficiency for students beginning their capstone project is lack of previous team experience [4]. Experience leading teams, communicating with clients and motivating team members as coupled with project management and time management skills, typically categorized as professional development, are reported as the most commonly taught content in capstone courses as the students prepare for their futures after graduation [5, 6, 7]. While students are provided opportunities to hone their professional development skills through real-world capstone projects, assessment of student achievement regarding these skills remains a challenge in capstone programming.

In a recent study, engineers were interviewed at intervals of 3-, 6- and 12-months post-graduation regarding their expectations in a new industrial job [8]. New engineers voiced challenges in the areas of 'learning new domains' and 'managing their time among multiple projects'. Self-guided learning sits at the core of all other professional development skills (see Figure 1) and shortcomings in this area remain a challenge graduates face when entering the workforce [8].

These findings provide value in the exploration of an alternative type of capstone senior design in the form of a design studio model, wherein the students can gain experience in self-guided learning, time management and prioritization of deadlines and deliverables across multiple projects. While seniors expressly develop project management and time management skills in a typical capstone course, a design studio creates a unique environment for learning in these areas. The greatest difference between the typical capstone model and the design studio model we outline here is the requirement that students participate on a minimum of three different projects, possibly overlapping, over the course of two semesters, fundamentally changing how students experience their design project timelines. We believe that this core innovation of our studio provides broader project and team exposure, deepens project management knowledge and skills and creates a well-rounded engineer better prepared to enter the workforce.

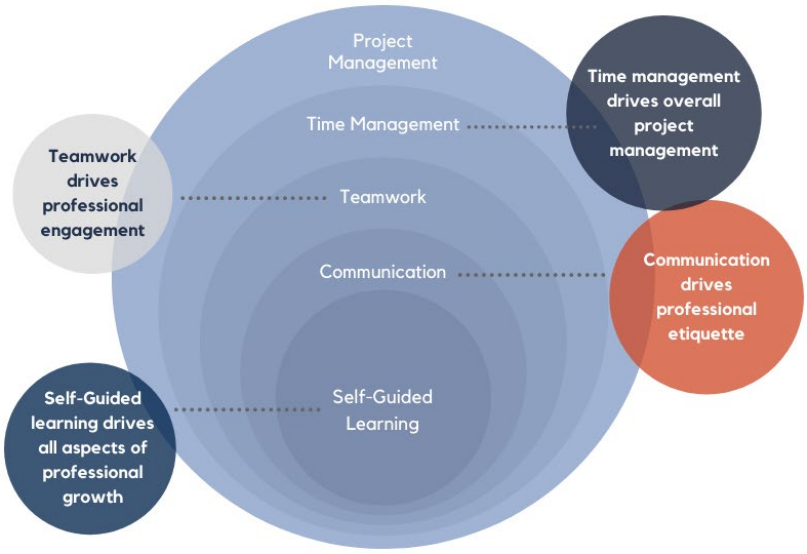

Figure 1. Self-guided learning sits at the core of professional development skills taught in many capstone programs [6] [8]. The design firm capstone studio model targets self-guided learning as a meaningful area of student growth and career development

Capstone Course Structure

The capstone senior design program at the Colorado School of Mines is a multidisciplinary senior design program supporting 500+ students every year. Disciplines served within the program include Civil Engineering, Computer Science, Design Engineering, Electrical Engineering, Environmental Engineering and Mechanical Engineering. Our capstone program is well supported by diverse project clients, including industrial sponsors, local community members and individuals. A small number of general 1-hour capstone lectures, focused on professional development skills, are offered over the two-semester course sequence. Classes are held twice a week, three hours per day (including the occasional lectures), where students can work on their project, hold formal design reviews with their clients, brainstorm, design and build. Students are also encouraged to complete project work outside of these scheduled time blocks.

The Human Centered Design Studio (HCDS) serves as an alternative pathway within our capstone ecosystem. Noticing the limitations in student professional development in a one-team, one-client, one-project constrained to an 8-month academic calendar model, the HCDS model arose to maintain the learning outcomes of typical capstone but provide a distinctive experience. The HCDS model entails four pillars of distinction that enhance students' learning experience: a) service on multiple projects over two semesters, b) service as project lead, c) semi-vertical integration with first and second-semester

seniors consistently rotating through the studio and d) ability to complete course learning outcome requirements through a modular approach.

Abiding by the design studio principles outlined above, maintaining consistency in the completion of the general capstone course learning outcomes and allowing for flexibility to service the immersive design experience required creativity in structuring course content. A modular approach to delivering content associated directly with seven phases of design, described in detail below, was adopted to ensure all course requirements were met. The HCDS model strives to deliver a robust approach to student learning and development in three key areas: communication, time management and project management. Student self-assessment of their experience in the studio environment resulted in positive evaluation of growth in the areas outlined above.

Design Studio Requirements

Our design studio model was created with four pillars of distinction, as overviewed in Figure 2. Each of the pillars is required to capture the design studio practice in its breadth and craft a unique and fulfilling experience for the participating students.

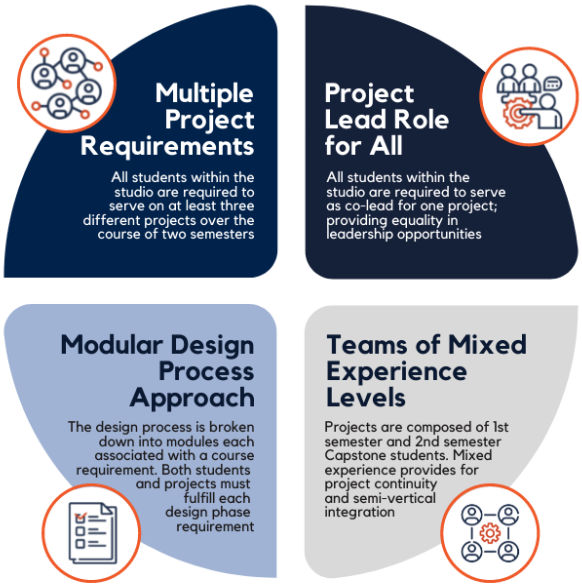

Figure 2. The four pillars of the design firm capstone studio model establish consistency in the model, continuity of projects, satisfaction of clients and most importantly a student experience crafted to generate exposure to an immersive and dynamic design environment mimicking a design firm

Service on Multiple Projects

Students are required to serve in some capacity on a minimum of three different projects over the course of their two-semester tenure in the design studio. Given this requirement, students often participate on a couple of projects simultaneously, yet the design phases completed for those projects during the

semester may differ. The multiple-project requirement provides students exposure to variability in clients, client engagement, project scope, project needs, team members and project timelines. Working across multiple projects serves as the cornerstone for the design studio model. The dynamic and immersive environment in the design studio is achieved through immersion on multiple projects at different stages of design and encourages student self-guided learning and subsequent growth in all professional development skills (Fig 1). Students entering the studio serve on a project in progress immediately and will often also join other projects in early stages of problem definition. The dynamic aspect of the studio is honed through student service on multiple projects with varying timelines, varying clients, varying teammates and varying solution spaces. Whereas, the dynamics of typical capstone courses are achieved typically through a one-project, one-team, one-client model.

As described by Howe, cultivation of a 'capstone ecosystem' is of great importance to foster student development prior to graduation and dissemination into industry [2]. She explains that one method for creating such an environment is that of cross-project team discussions. Cross-project discussions can enhance open-lines for communication, brainstorming, design critique and development of professional skills. It is in this format that we strive to create a truly collaborative space in the design studio model. Typical capstone teams achieve some of these team dynamics through working with each other, the extent of which can be limited to an average of five other team members. With the studio model reaching numbers upwards of 60 participating students, across 20+ different projects, all at different stages in the design process, cross-project discussions are prominent in our setting. Our HCDS classroom can accommodate multiple groups working in parallel—concepting, prototyping, testing—allowing for fluid movement between teams by other students and faculty. Furthermore, our projects are enhanced when students participate on a project having prior knowledge of a similar phase in the design process from another project, or an alternative solution space, or a suggestion for overcoming a project roadblock.

Service in Role of Project Lead

Capstone has been identified as a space whereby students engage in teamwork and project management development [5]. Maintaining the importance of these traditional capstone pedagogical approaches, the role of project lead remains a mainstay in the design studio. As is often noted however, particularly in STEM/PBL or team-based learning environments, women tend to absorb much of the communication and written documentation work, while men gravitate toward the tasks requiring greater technical skills and project progression [9]. Additionally, students who may be more confident in their skills or leadership tend to take on higher profile roles, leaving the quieter or less confident students in a more supporting role. Inasmuch as we can foster a more equitable environment, we require that all students serve as a project lead on one of their three projects. We believe that this experience not only nurtures communication and technical growth for the student serving as project lead, but it also allows for student personal growth through accepting team roles they may not voluntarily select without this expectation. In many instances, given the large number of students in the studio (~60 students/semester) the lead role is shared between two students, whereby tasks are assumed by the leads and delegated amongst the teammates. Student participation as lead is tracked and provides an assurance that students are engaged in project progress and aiding in team development. This experience also opens students up to the capabilities of their classmates.

Mixed Experience Levels

The dynamic nature of first semester students cycling into the studio and second semester students advancing to take the more senior roles achieves a degree of semi-vertical integration. More senior students within the studio provide mentorship, often as a project lead. Their experience with the design studio model creates an openness and collaborative environment for newer students unsure of how to progress in a new team or on a project mid-design phase. While design studio instructors create an open environment for student participation in communication and design, the senior student members of the studio provide a different and often more equitable exchange and collaborative experience than can be achieved between students and instructors.

Modular Design Process Approach

It is highly unlikely that an engineering graduate will join the workforce and begin day one of their new job at the exact start of a new project. Instead, they are more likely to join a project already in motion, requiring from them the discipline and self-guided learning skills to ask questions, conduct research, investigate prior project documentation and build the knowledge base needed to participate effectively in on-going projects [8].

The design studio model requires students to enter projects at various stages of completion, as in industry, to aid in the development of project orienting skills. This particular skillset is nowhere taught for our students except in HDCS. Given the on-going movement of students between projects, we have created a structure to facilitate continuity. Continuity is required in the instance of students graduating and others moving onto projects, or in situations where students may move off a project to complete other phases of design on a different project. Alternatively, documentation is critical to maintain a sense of continuity if a project is completed and the client returns requesting an updated design. Completion of a project is dependent upon the achievement of each of seven steps within the design phase, separated into distinct elements for our students. In addition to tracking *project* design phase completion, we also track student participation in each design phase to ensure they participate in every design phase regardless of project or sequence. For example, a student might join a team and complete moderate fidelity prototyping and engineering analysis first and then subsequently lead a team on a new project requiring background research, client interviews and solution brainstorming. This module approach allows for faculty to assess student course completion even if out of sequence and provides a pathway for students to monitor project progress as well as their own academic progress through the course.

Managing Learning Outcomes in the Design Phases

The dynamic nature of the design studio and requirement to service three projects over the course of two semesters facilitates creativity in positioning and assessing the course learning objectives. In establishing the design studio, the faculty were sensitive to the three-project requirement such that our students were not completing triple the amount of work of their peers in the traditional capstone course but were nevertheless fulfilling course learning outcomes and enhancing their experience through each project and phase of the design process.

Review of the 2015 capstone programmatic survey of ABET accredited institutions demonstrated that most programs evaluated focused coursework on assessing completion of both product and process, with process often the main indicator of course satisfaction [1] [4]. Utilizing the design process as a spine for

curricular requirements allows for easily articulated design milestones. Design milestones within capstone programs is not new. In fact, they are being used increasingly to establish a framework for student and project progression [10]. After review of other capstone program objectives and assessment protocols, a design phase milestone model which monitors student progress through the course with targeted learning outcomes was adopted. More specifically, the model in our design studio facilitates student assessment and fulfillment of course objectives through learning outcomes associated with seven phases of design. Each student *and* project within the studio must demonstrate completion of each phase with supporting documentation. Figure 3 outlines the seven design phases used in our studio.

Figure 3. The design firm capstone studio model makes use of milestones or design phases to ensure students' progress through all phases of the design process and meet course requirements

These design phases are outlined in our course learning management system (LMS) application, Canvas. Each of the seven distinct phases of the design process culminates with one written or oral deliverable as mapped to our course learning outcomes. Outlines of the design phase step within Canvas are coupled with readings and short video explanations of content students can use to generate their formal submission. For example, phase 3, 'Identifying and Evaluating Solutions', contains asynchronous, 'Learning Activities' and non-graded 'Pre-Work' suggestions to guide the team development of their graded assessment content, as seen in Figure 4.

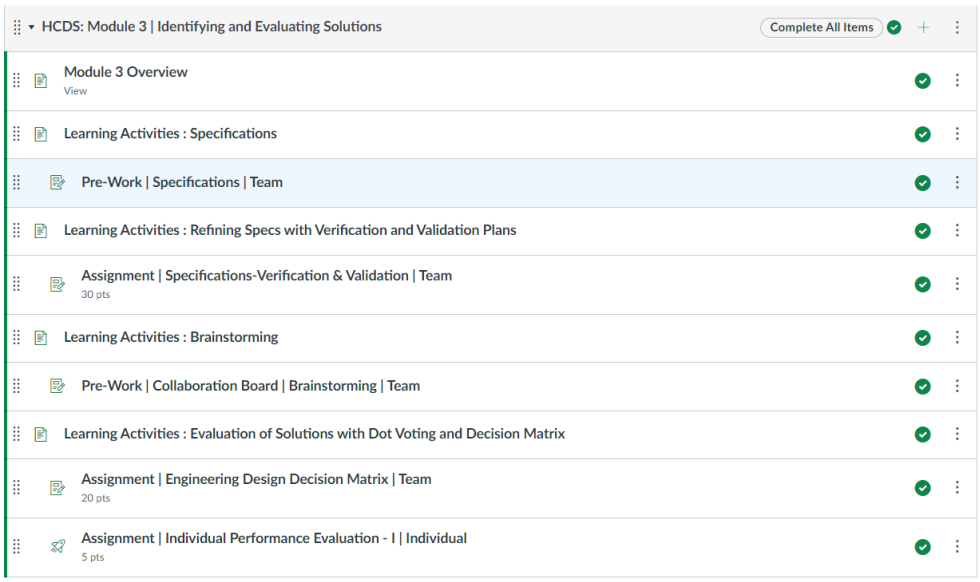

Figure 4. Example of coursework to facilitate student self-guided learning through proposed Learning Activities, Pre-Work guides and formalized assignments

Through accomplishment of each phase, the students complete course required learning outcomes, fulfill program required ABET assessment outcomes and work their way through the design process. As each project is also broken down into distinct phases of the design process, documentation and continuity of team members provide evidence of percent project completion as related to achieved and remaining phases. Both individual design phase completion and project specific phase achievement are tracked via an Excel spreadsheet and available for students within the design studio. Therefore, students and faculty understand both project status and individual design phase coverage needs when joining teams to ensure they meet course requirements. Students are encouraged to reference prior project documentation and begin orienting themselves to their new projects during team meetings, enhancing the development of their self-guided learning [8].

As students within the design studio do not necessarily start at phase one or end at phase seven, the milestone model aids not only in ensuring projects move through each phase of the process but also in the onboarding of new students in the middle of an ongoing project. Asynchronous learning content has been developed for each stage of the design process within our module layout, which establishes a framework for the specified phase, orients new members and facilities project on-boarding. Project documentation of all module assignments provides background information regarding the client, needs, project scope, solution selection, verification and validation plans, engineering analysis, proof of concept, bill of materials, user manuals, testing results, iterative design work and finalized solution design and development. Archived documentation coupled with team continuity aids in the continuous iteration, development and finalization of projects within the design studio.

Design Studio Course Organization

The design studio model rests on the four pillars outlined above and a dynamic, modular approach to delivering and assessing required learning outcomes. The fitness of this model in developing student skills particularly in communication, time management, project management and self-guided learning

are achieved through consistent delivery of course touchpoints. Concretely, the design studio model manages the fluidity and flexibility of the pillars and modular learning outcomes through structures aimed at achieving reliable student experiences in project selection, stand-up meetings and documentation. The fluidity, flexibility and consistent delivery of course objectives and experiences require significant dedication from the faculty team.

Project Selection

At the beginning of each semester, students joining HCDS are asked to review both in-progress projects and new projects. New projects are presented to the large class of both first and second semester seniors with information pertaining to the client, the user, a general overview, disciplinary requirements and anticipated team size. On-going project pitch videos are created and compiled by returning members of various project teams. Each project pitch video includes all the pertinent information of a new project as well as the current project status, including design phases completed. After review of both types of projects, students can select to be added to a *MS Teams* project group for further information gathering and evaluation of the team, project and needs. We value student flexibility in project selection and encourage students to explore many different projects over the course of the first two weeks of the semester, before down-selecting to one or two projects for which they feel the most passionate. This flexibility provides more security in the student selection process and fosters an environment of excitement [9]. During the semester, there are times when new projects are pitched to students in a similar fashion. The ability to start projects outside of the beginning of the semester provides a model for client engagement and project planning that is less constrained by the academic calendar.

Over the past five years, there has been only one instance where faculty needed to step in to request a team downsize. Often students will seek out projects with priority given to 1) their passion for the topic, user or client and 2) the project's required design phase modules. In other words, if a student has already completed design phases 5-7 on a given project, they will look to serve on another project or projects requiring design phases 1-4 to be completed. The fulfillment of the multiple project and design phase requirements creates a natural distribution of students onto projects with teams averaging six students each. Similarly, the requirement that each student serves as a lead has been easily and organically satisfied. This is likely due to the number of students entering the studio in the fall (~40) versus the spring semester (~20) and the number of projects offered each semester. Students have sought the lead role on projects for which they feel most passionate or will take over the lead role on a project for which they are serving in a second consecutive semester. The model has proven easy to navigate with high levels of student participation.

Stand-up Meetings

Proponents for the studio learning model argue that students learn best when undertaking 'reflection-in-action' [11]. Fostering a sense of continual reflection, design and iteration requires appropriate faculty involvement. Through trial and error, we have discovered that the best method of course-wide oversight entails quick 'stand-up meetings' [12] [13], whereby faculty assume the role of technical advisor and facilitate an 'equitable dialogue' [14] in which our contributions are weighted equally to those of the student team members. Each team is required to attend a bi-weekly stand-up meeting with a prepared document reflecting on questions we have provided to assess their project progress. The stand-up meetings create a space for open communication and allow for instructor guidance regarding time and project management.

Oral and Written Deliverables

Each step of the design phase requires the completion of a team-based oral or written assignment. Additionally, the course requires individual assignments to fulfill program requirements in writing, peer evaluation and reflection on learning. Team-based assignments contribute 55% of the overall student grade, with individual assignments making up the remaining 45%. While assessment has been identified before as a challenge for studio models, particularly in assessing individual student contributions, each team and individual assignment is graded on a rubric developed for the capstone course as a whole, enabling consistent grading across both the traditional capstone students and the studio students [12] [15, 16]. To ensure that students are experiencing the full breadth of the design process, all students are graded upon their completion of the entirety of the outlined deliverables over the course of two semesters, independent of order of completion.

Results and Discussion

Evaluation of our design studio model and student experience was formally examined over the course of a semester in HCDS in the spring of 2021. Surveys were administered to evaluate pre-HCDS baseline experience (at the beginning of the semester) and post-HCDS experience (at the end of the semester) as self-reported by students. The group surveyed was composed of a mix of first semester and second semester HCDS students. Questions involved their self-appraisals of their professional skill experience levels in the areas of communication, time management and project management.

Student Reflections on Their Design Studio Experience

As a whole, students reported consistent modest improvements in their self-assessed communication skills over the course of the semester in HCDS. Students identifying as ‘slightly above average’ increased from 19.4% to 21.4%, those identifying as ‘above average’ increased from 48.4% to 50% while the categories of ‘average’ and ‘slightly below average’ in communication decreased by 0.4% and 3.2%, respectively. Results can be seen in Figure 5. Overall, we noted an increase in student self-assessments regarding their ‘above average’ communication skills of 10.3%. Those students originally identifying as ‘slightly below average’ relayed a similar sense of improvement over the course of the semester.

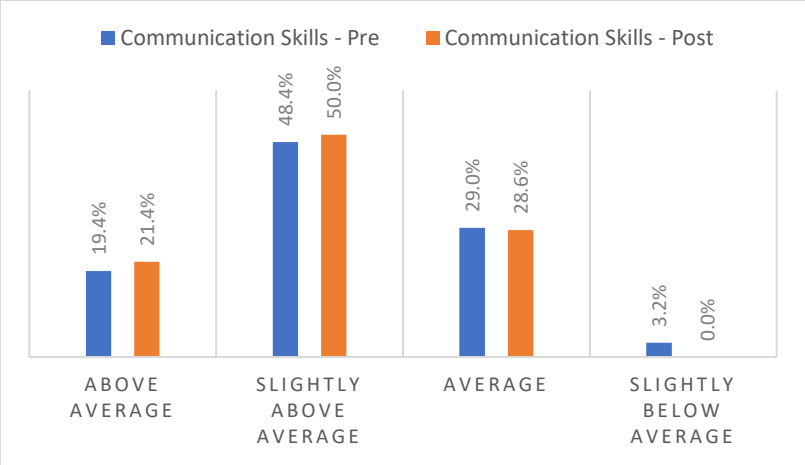

Figure 5. Percent of students evaluating their communication skills before and after one semester of the HCDS design studio capstone model

Similarly, students reported an improvement in the self-assessment of their time management skills, achieving the 'above average' category with an increase overall of 44% between pre and post survey. The data also indicated a 17% increase in students identifying as 'slightly above average' between pre and post. Interestingly, a 10% increase in students identifying as 'slightly below average' was noted during this data collection. We can speculate this change results from some students reevaluating their competency in this area as a result of the increased uncertainty characteristic of design challenges compared to their other courses. Results can be seen in Figure 6 below.

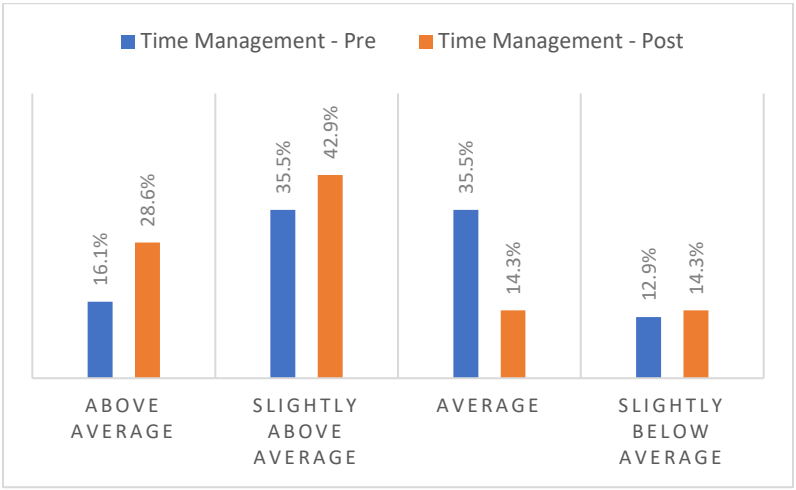

Figure 6. Percent of students evaluating their time management skills before and after one semester of the HCDS design studio capstone model

Student self-assessments of their project management skills demonstrated the greatest divergence in terms of improvement (Fig. 7). Categories of students identifying as 'slightly above average' or 'average' both significantly decreased from pre to post survey, however, the categories of 'above average' and 'slightly below average' both increased by 73% and 85%, respectively. The data collected from this survey demonstrated the greatest improvement among the skills measured, in part supporting

the model as a platform for continuous improvement in the professional skills. Yet, the data also indicates the largest decrease in self-identified professional development. Further data collection is required to understand this divergence, but an initial exploration of the data is provided below.

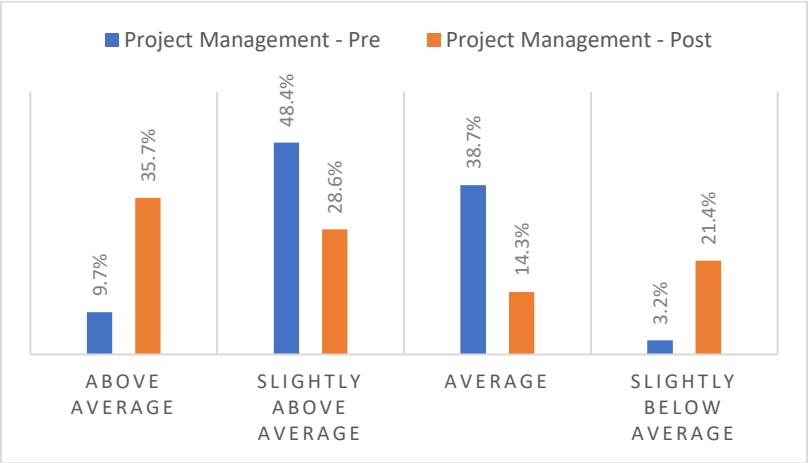

Figure 7. Percent of students evaluating their project management skills before and after one semester of the HCDS design studio capstone model

While student responses supported growth in the areas of time management, project management and communication after participating in the design studio model, there were noted divergences in the data collected. Student participation in the survey was reduced in the post-HCDS reflection with response numbers in the pre-survey of n=31 vs. n=14 in the post-survey. Furthermore, as the survey collection was optional, not all the enrolled 60 students opted to participate, impacting the amount of data collected during this cycle. We did note an increase in the percent of students response pre:post for time management (12.9%:14.3%) and project management (3.2%:21.4%) in the category, 'slightly below average'. As the participation in the post survey was less than half that of the pre survey and collected during a COVID semester, truncating the data collection to only the spring semester and not an entire year of design studio experience, the variability could explain the deviation limits. However, the discrepancy seen between those identifying as 'slightly below average' in project management skills in pre and post surveys is deemed significant. Follow-up student interviews were conducted to determine how faculty could better serve the development of project management skills of our students in the design studio. Student leads responded that the areas needing improvement regarding their management of projects included client and user engagement in project feedback, on-boarding strategies for new team members, identification of roles and responsibilities and clearer project requirement documentation.

Beyond the Likert assessments, students were asked to describe an engineering or professional skill they honed while serving on multiple projects within HCDS and how those skills might translate to their career. While identification of growth in technical areas were occasionally identified and described, most students reflected on their professional growth, specifically in the areas listed below. Sample quotations are used to illustrate these skillsets as described by students.

Communication:

"Communication. Communicating what I am working on, when I need help, and making sure that I understand what I am supposed to be doing. I think it will translate to my career because any time I am working with or for other people, which is basically the point of engineering, I will have to be able to communicate clearly and make sure I understand what is being told to me."

"I honed my communication and collaboration with multiple teams to effectively manage a variety of challenges. This will help when I have to communicate with multiple parties at the same time."

Time Management:

"Time management, working on several projects in HCDS will help me to manage my time well professionally and meet project deadlines."

"Time management. Professionally I will most likely be working on multiple projects at a time and having this skill would make it easier to complete them all."

Project Management/Leadership:

"A profession skill I honed was project leadership (management). I've worked very hard this year to keep my project on track and communicate the deliverables effectively to my team. I think this will be very useful for my career as an EMI engineer in aerospace. I will have to communicate effectively with several groups at my company."

"I developed my project management skills, as I was able to organize and delegate tasks to efficiently use our team's resources."

Collaboration and Teamwork:

"I mostly gained collaboration and planning skills. Obviously, this will be useful when working on projects with multiple team members in the future."

"I think working with different groups of people and learning about how to work to maximize the benefits of everyone's strengths will help me with any team I work with in the future."

Overall, students queried after a semester participating in the HCDS design studio capstone model identified that the design studio requirements prepared them for their careers post-graduation (Fig. 8). As indicated through student written reflections and student interviews (excerpts below), the design studio model services the students in their growth as focused on self-guided learning, communication, time and project management.

"Dealing with clients. I feel like I got both sides of the spectrum with one client who gave zero feedback and one that gave way too much. This really helped me to learn patience and I think in the future of working with other clients it will help me to be ready for any situation."

"I have honed so many skills! My time management, leadership, Solidworks, design, and communication skills have all just increased. This I already know has made me a better person and a better engineer. I will be able to deal with several projects and groups with ease. This is exactly what I think will occur in industry."

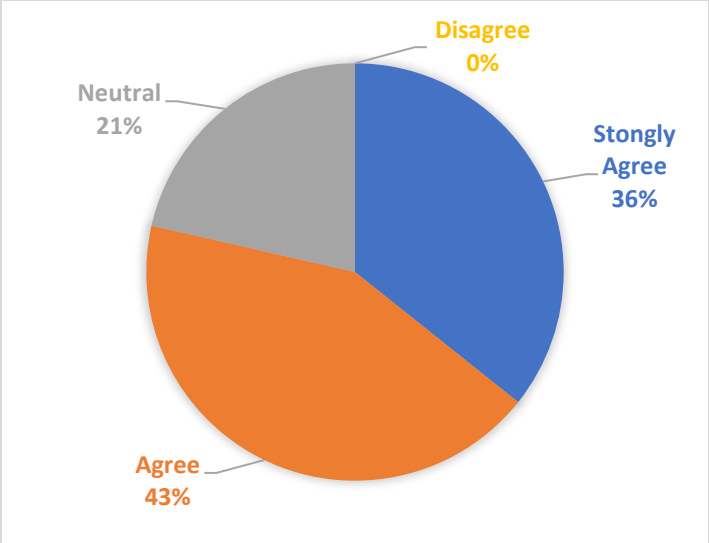

Figure 8. Student evaluation of the design studio model on preparation for industry

Client Assessment of Student and Team Performance

Client feedback has been overwhelming positive regarding team progress and completion of projects. As most of our clients are individuals or companies directly deploying the equipment produced in our design studio, the iterative process is paramount for proper product development and assurance of meeting user specifications. Clients favor the studio model and the ability to provide feedback for project iteration and improvement unconstrained by the typical 8-month capstone senior design model. Client feedback was assessed in an online survey. In the words of one of our clients:

"I believe every single team we worked with has been very communicative and when the project is handed off to the next team members, they pick up the coms right away. I realize many of the projects that they have tackled for our organization have been somewhat tedious and nearly impossible to finish in a term, therefore necessitating new leads and teammates."

What Others Can Learn

The design studio model requires student and faculty commitment to ensure successful implementation, but this commitment pays back through organic learning experiences, cross-team collaborations and sharing of skillsets. Students and clients positively evaluate students' professional growth through management of multiple projects, timelines, clients and teammates. Most important to the immersive and dynamic design studio experience is the course's integration of modular learning outcomes and assessment measures. The modular learning environment overcomes challenges resulting from the multi-project format when learning outcomes presume a traditional 8-month single project cycle. Like industry timelines that extend past 8-months and require multiple phases of iteration, the design studio model delivers the needed flexibility, while still maintaining student academic progress. Ultimately, the complexities of the dynamic design studio model mirror the complexities of real-world design, thereby facilitating an immersive experience that builds student confidence in self-guided learning and life beyond the classroom.

Future Work

Beyond the qualitative reflection on student growth lies quantitative assessment of outcomes achieved. In building off the scope of this analysis, it would be worth investigating how students in the design studio model compare to their counterparts in the typical one-team, one-client, one-project capstone design experience. Exploring student experience in their depth of project knowledge as coupled with their achievement of course outcomes would aid in the understanding of possible limitations in the design studio model. Additionally, given the strengths of the studio model identified above, it would be worth exploring how the design studio model could advance the achievement and assessment of ABET outcomes as related to teamwork and continuous learning. Finally, while traditional capstone design models effectively address the ABET requirements of '…ability to acquire and apply new knowledge as needed…', it would be interesting to assess the four pillars of our capstone design studio model in terms of this same outcome. The dynamic nature of a design studio and experiences associated with multiple projects, multiple clients, multiple teammates create a robust environment for self-guided growth.

Conclusion

Over the past five years, the design studio model of HCDS has continuously developed and iterated. Like any good design challenge, we have worked directly with our student stakeholders to ensure their experience is one that provides depth and breadth, rigor, excitement and meets the institution's capstone course requirements and ABET requirements. The small changes made each year have informed the pedagogy of the studio model. For example, we have incorporated a better-defined project timeline through deliverable deadlines and design critiques. Our students maintain a healthy balance of project challenges and rewarding interactions with teammates, clients and instructors. We believe that it is in the stand-up meetings, close working environment and opportunity for exposure to multiple projects that makes our studio not only unique, but a sought-after senior design experience. It is in the studio pedagogy that students learn best through continuous interaction, reflection and overcoming challenges [11, 12] [16] [17]. We believe that we have created an interesting alternative capstone experience that challenges students to hone their time management, project management and communication skills through a unique multi-project, multi-client, multi-team model.

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