Organizational Design and Delivery of an Interdisciplinary, Client-Sponsored, 2-Semester Capstone Experience

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This paper contributes one case study to the scholarly record by providing a programmatic overview of Capstone Design@Mines (D@M). D@M delivers a project-based, two-course senior design sequence for Mines' undergraduate majors, serving over 500 students every term. D@M students work on interdisciplinary teams to design solutions to client-sponsored, client-supported challenges. Rather than focusing primarily on our program's curricular goals or educational outcomes, this paper focuses attention on how we bring together diverse organizational resources into a coherent, repeatable, streamlined educational experience. Key resource domains that will be addressed include project portfolio management, instructional resources, and organizational support. By providing such a programmatic overview, this paper will explore the organizational design dimensions of interdisciplinary educational capstone program delivery at scale. We also share our program's future directions, including efforts to increase the degree to which the program is financially self-sustaining.

Keywords: Capstone delivery, industry collaboration, interdisciplinary programs, organizational design

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Introduction

A capstone design experience is required for graduation by almost all US engineering programs. This leads to a dizzying array of approaches to capstone design, including numerous interdisciplinary programs managed outside of the disciplinary engineering departments they serve. Despite their ubiquity, capstone design programs are often ill-understood by those faculty members who do not participate directly in their delivery. Because of their ubiquity and the wide range of approaches to delivering capstone experiences, even those faculty who do participate in content delivery do not necessarily consider the organizational dimensions shaping their own or others' programs.

This paper contributes one case study to the scholarly record by providing a programmatic overview of Capstone Design@Mines (hereafter, D@M). D@M delivers a project-based, two-course senior design sequence for Mines' undergraduate majors, serving over 500 students every term. D@M students work on interdisciplinary teams to design solutions to client-sponsored, client-supported challenges.

Rather than focusing primarily on our curricular goals or educational outcomes, this paper focuses attention on how we bring together diverse organizational resources into a coherent, repeatable, streamlined educational experience. Key resource domains that will be addressed include project portfolio management (e.g., client engagement, sponsorship and financial models, IP and NDAs, project diversity, project scoping and timelines), instructional resources (e.g., faculty, project advisors, client mentors, online learning tools, instructional facilities), and organizational support (e.g., staff roles and administrative support, leadership structure, inter-departmental collaborations). By providing such a programmatic overview, this paper will explore the organizational design dimensions of interdisciplinary educational capstone program delivery at scale.

Program Structure

D@M supports curricular requirements of capstone design for five undergraduate engineering degree programs: civil, electrical, environmental, mechanical, and our unique design-focused "engineering" program, together accounting for approximately 45% of the graduating seniors across the 12 undergraduate engineering programs at Mines.

D@M entails a two-semester course sequence with approximately:

- 15 weeks per semester dedicated to course content and deliverables;
- 25% of the total 30 weeks dedicated to general lecture and recitation material;
- 12% of the time dedicated to high-level project work – project selection, client kickoff meeting and critical client review meetings, and students showcasing their project work; and

- 63% of the total course contact time is allocated to project-dedicated work.

The Spring 2022 semester included projects that started Fall 2021 and will be completed May 2022 as well as a smaller number of projects that started Spring 2022 that will finish December 2022. In this semester, the program supported:

- 533 senior students (117 or 22% students in 1st semester and 416 or 78% students in 2nd semester);
- Over 71 unique projects (16+ projects in the 1st semester and 55+ projects in the 2nd semester);
- 44 unique clients, 36 of which are external to Mines (companies, government agencies, NGOs, and individuals);
- 11 projects characterized as intercollegiate challenge or competition projects; and
- 4 Design Studios potentially allowing students to work on multiple projects on project cycles that diverge from the typical academic calendar, including Human-Centered Design Studio (adaptive technologies), Smart Environments Design Studio, Engineering for Communities Design Studio, and the Newmont Goldcorp Innovation Challenge Studio (mine reclamation).

The distribution of students across these different project categories is approximated as follows:

- 50% working on stand-alone projects;
- 20% working on challenge and competition projects; and
- 30% working in Design Studio environments.

Resources applied to support this program include:

- Faculty & staff: Program Director (60% FTE, currently vacant) plus four Core Faculty where this course sequence represents 2/3 of their course load, 26 faculty Project Advisors (includes the core faculty group), a Stakeholder Relations Manager, a Program Assistant (25% FTE), a Purchasing Support person (25% FTE), and 3 lab TAs.
- Design/Build spaces: Six dedicated lab spaces totaling approximately 8,000 square feet.
- Program Financial Support through Mines Foundation contributions and external client sponsorship fees.

Programmatic Features

This section highlights how D@M is organized and run, including course continuous improvement, instruction, project funding, and student team advising.

Leadership Team, Instructors, and Support

Because the program accommodates over 500 students and over 70 unique projects each year, the course has an umbrella leadership team of five faculty who oversee the course and administration of the projects. The C@M Director (vacant; formerly co-author Persichetti) manages the program and handles all administrative functions from hiring of Project Advisors to initial scoping of projects to formation of student teams. The Stakeholder Relations Manager, an administrative position, serves as the primary contact for clients and coordinates the scoping of projects throughout the year. Four Core Faculty, one from each department offering the primary disciplinary degrees covered by the program, oversee the course development and instruction, facilitate the group of 20+ Project Advisors, and assist with scoping projects related to their disciplines. Projects Advisors (PAs), most of whom are practicing engineers and some of whom are regular faculty members, mentor and monitor the student teams through the 8-month project cycle.

Each PA typically advises four teams (~5-8 students per team) and is responsible for meeting with the teams for general advising and design reviews and for grading all individual and team assignments. In all, the program has a team of over 30 faculty that serve in administrative, instructional, and/or mentorship roles.

Course Structure

The D@M two-semester capstone design sequence provides six hours of weekly class time for the students, with two hours initially reserved for lectures and four hours of recitation reserved for team project work and team meetings. The first several weeks of the course include lectures that range from project management to ethics to communication. Around midterm, the full six hours are reserved for teams to meet and work on their projects.

The primary team assignments include a Letter of Intent and Preliminary Design Report in the first semester and, in the second semester, the Intermediate and Final Design Reports and the Design Showcase presentation at the very end of the cycle. Individual assignments include video modules on design and project-management related topics and writing assignments on ethics and broader impacts in the first and second semesters, respectively. The agile method of scrum is used as a project management tool for all teams, and PAs are expected to work with teams in practicing the recurring 2 to 3-week sprint cycle.

Continuous improvement of the course is facilitated by weekly meetings of the Leadership Team and monthly meetings with the broader group of PAs. The Leadership Team oversees administrative needs of the program, including new projects on the roster, coordinating of

larger events (e.g. the Project Expo at the beginning of the project cycle and the Design Showcase and the end), and potential challenges with teams and/or project clients. Meetings of the Leadership Team with the PAs are used to overview the classroom activities during early recitations and facilitate discussion of grading assignments. Common to both the Leadership Team and PA meetings are opportunities to improve course material, including lectures, recitation activities, and course assignments.

Resource Model

D@M enjoys a broad base of program support, including university instructional support for adjunct PAs, department support for full-time faculty to participate in the program, and administrative support from D@M's administrative academic home, the Department of Engineering, Design, and Society. The staffing structure has evolved to support of the scale of the program from just over 300 students in 2016 to well over 500 students in 2022. In this same timeframe, the Leadership Team grew from two to four faculty plus the Director (with no teaching requirement), the Stakeholder Relations Manager, and 50% FTE support staff for purchasing, student travel arrangements, and finances. University funding for non-regular-faculty project advisors is a clear distinction from other large programs that traditionally rely on full-time instructors to advise teams and grade student work. This allows us to integrate extensive industry experience within our program's instructional team.

While the program's instructional and administrative staff are supported directly by the university, student projects are supported exclusively by donors and project clients, with student teams provided a budget of between $500 and $2500 for materials and, where necessary, travel. Rarely, teams are allowed to exceed this limit when additional funding is available, such as when clients allocate additional project funds or for some externally supported competition projects.

External Sponsorship: Donors and Project Clients

The program follows an industry-funding model of $5000 per project for those clients that can afford the sponsorship. We also have a number of community-based and non-profit-sponsored projects, where the client is forgiven the regular client sponsorship fee but is sometimes invoiced for materials at the end of the project. While some competition teams are funded by their hosting organizations, e.g. Shell Ecocar Marathon, others are not, including Hyperloop and NASA challenges. Some student teams work with the Mines Foundation to crowdfund their project and travel expenses, with successful project teams fundraising anywhere between $1000 and $20,000. Finally, D@M has enjoyed ongoing support from one private donor at $25,000 per year.

As of 2022, the financial snapshot for the program approximated the following:

- 25% of clients paying a sponsorship fee commensurate with their organization type, with up to half of the sponsorship fee allocated to direct project expenses and the remainder used for general program support;
- 12.5% of clients reimbursing Mines for materials costs, but not paying any additional program support;
- 12.5% being competition projects funded through the Mines Foundation and external donor support;
- 20% of clients as government agencies (federal, state, or local) that are not charged a sponsorship fee, occasionally covering projects' material costs;
- 20% of clients are Mines faculty or Mines internal organizations, each covering their own project expenses; and
- 10% of external clients who cannot pay a sponsorship fee but whose projects are accepted to the program as a "giving back" to our community.

Client Partnerships

Client partnerships are a win-win for our program, benefiting students and clients alike, not to mention bringing regularized positive press to the university and modestly supporting our program's overhead. Clients range from large companies (e.g. Sierra Nevada Corp. and Honeywell) to local community and government partners (e.g. Craig Hospital, the City of Golden, and local park services). We also have a large number of international humanitarian projects supported in coordination with Mines' acclaimed Humanitarian Engineering program.

D@M maintains some capacity to support individual clients as well, including faculty with sponsored research projects appropriate for undergraduate design students and local entrepreneurs who need assistance developing their technologies.

For clients that require a non-disclosure agreement (NDA) and/or for those who require retaining intellectual property (IP) rights, we provide a university-approved template for clients to use with their student teams. These templates were developed in partnership with our Office of General Counsel. At Mines, the university does not claim IP for student projects associated with their normal courses, so undergraduate students own their work except where clients utilize NDA/IP protections. Students are informed of any NDA/IP requirements before they select their top project choices, and they are moved off of projects requiring NDAs/IP agreements if they are not comfortable waiving their rights by signing these agreements.

Overall, our students and our program benefit from real-world problems from industry and the community, while clients gain a potential solution to their problem and a vetting opportunity and potential pipeline for future hires.

Future Directions

The 2021-2022 academic year has shown continued growth of the D@M program along with steady enrollment growth in the associated majors, including the 2018 launch of our design-focused Bachelor of Science in Engineering major. We project the program to grow to over 600 students over the coming three years, reflecting continued university enrollment trends, including a spike in enrollment during the COVID-19 pandemic.

Along with projected growth due to enrollment, an effort is also underway to expand the D@M model to other engineering degree programs as Mines. Already, the Capstone Design@Mines Senior Design sequence can be accepted as an alternative to senior design requirements in other departments, with a department's case-by-case approval. Currently, the D@M course sequence is routinely accepted by Engineering Physics, providing a design-focused alternative to their standard capstone, which is research and publication focused. D@M is currently working toward program and topical project expansion to support senior design in Computer Science, Materials and Metallurgical Engineering, and Mining Engineering among others.

Regarding facilities, Mines has recently broken ground for construction of a 37,000-square-foot innovation complex and makerspace. The Labriola Innovation Hub will host dedicated D@M project spaces as well as fabrication facilities for metal, wood, plastics, composites, electronics, and print. The facility will be rounded out with ample space for collaboration, computing, and studying, along with a public café and presentation spaces. Scheduled to open in 2023, this facility will significantly improve access to cutting-edge fabrication for our D@M students while also providing secure space for their in-process project work. It will also place D@M more centrally within the university's public outreach efforts.

Programmatically, a key thrust is to become financially self-supporting for all expenses beyond facilities and full-time faculty/staff salaries. To that end, we revisiting our sponsorship fee structure with the goal of creating sponsorship tiers such as Sustaining Partner (tied to our Design Studios) and Endowment Partner (to recognize on-going relationships). Besides creating greater financial certainty and flexibility, additional sponsorship funds will be directed to student projects, which will leverage the Labriola Innovation Hub to create higher quality prototypes and conduct more robust testing.

Finally, with the recent retirement of our program director and the reorganization of our participating departments into different academic portfolios, we are exploring a variety of options for program oversight, including matrix reporting, a decentralized leadership model, and a rotational approach to program director from among the Core Faculty.

Conclusion

The Capstone Design@Mines program offers a fully scaled, interdisciplinary, client-sponsored, 2-semester design experience for over 500 students working on ~75 projects in an ongoing manner. With a dedicated Leadership Team, a modest set of additional support staff, a robust team of project advisors, and a diversified funding model, D@M offers an efficient and effective organizational model for delivering project-based learning for engineering seniors.

Our D@M team has invested considerable energy in creating and refining this organizational model, but has invested limited attention to sharing that investment with the broader scholarly and teaching community interested in capstone design approaches. This paper is our first effort to disseminate our approach and to join the scholarly conversations around the delivery of capstone design.