Enterprise: A Multi-year, Interdisciplinary Learning Experience at Michigan Technological University

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Described herein are the organization, curriculum structure, outcomes, and benefits of the multi-year, interdisciplinary Enterprise Program at Michigan Technological University. Launched in 2000 with funding from a National Science Foundation (NSF) grant (EEC-9872533), Enterprise focuses extensively on interdisciplinary, team-based problem solving. As an option to the traditional capstone design experience, Enterprise attracts students within and outside of engineering. Annual program enrollment has grown steadily and now includes 800 students from more than 30 majors – approximately 13% of Michigan Tech's undergraduate population. The Enterprise Program includes a diverse portfolio of 25 teams, each with their own identity, culture, and organizational structure. Team composition can include first-year through graduate-level students. Enterprise participation is linked with higher student retention and graduation rates as well as higher student perceptions of the program's impact on their teamwork, communication, and career preparation skills. Continued student demand, strong industry support, and academic rigor in meeting ABET student outcomes have enabled the program to be financially self-sustaining beyond the conclusion of the original NSF grant in 2002.

Keywords: Capstone, Interdisciplinary, Design, Enterprise

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Introduction

In the fall of 2000, Michigan Technological University introduced a new undergraduate engineering curriculum option intended to serve the needs of both students and industry. The Enterprise Program, initially funded through an NSF Action Agenda for Systemic Engineering Education Reform grant (EEC-9872533), provides teams of students from multiple disciplines the opportunity to work for several years in a business-like setting to solve real-world engineering problems. The program objectives are summarized below and were motivated by the need to improve professional and personal skills of engineering graduates.[1]

- Create an environment where students transition smoothly from their undergraduate program into the professional work force
- Provide opportunities to develop leadership and entrepreneurial skills in an environment that closely resembles a professional environment
- Encourage student ownership of a portion of their education that aligns strongly with their career goals
- Give students a taste of the rewards and accountability associated with creating new products and working with external clients/stakeholders
- Apply and integrate students' fundamental knowledge in science and engineering in the context of a problem where non-technical issues, such as cost or societal impacts, are of equal importance

Program design and structure

The Enterprise curriculum is two-pronged and consists of participation in an enterprise team (1-2 credits of project work per semester) and completion of concentrated course material (1-2 credit instructional modules) that helps develop valuable skills for successful team operation. Much like an industrial environment where an employee sets annual goals and development plans, students may select the instructional modules that best fit their personal and organizational goals. Students from any major can enroll as early as their second semester and can continue in the program to graduation; in 2014 Enterprise was further expanded to allow graduate student enrollment. Figure 1 summarizes the progression of the project work and the instructional module topics. Enterprise is available as a 12-credit concentration in all engineering degree programs. Other degree programs outside of engineering also have developed Enterprise pathway options, of varying credit levels, for their students. Additionally, an interdisciplinary 18-credit minor is available to all majors.

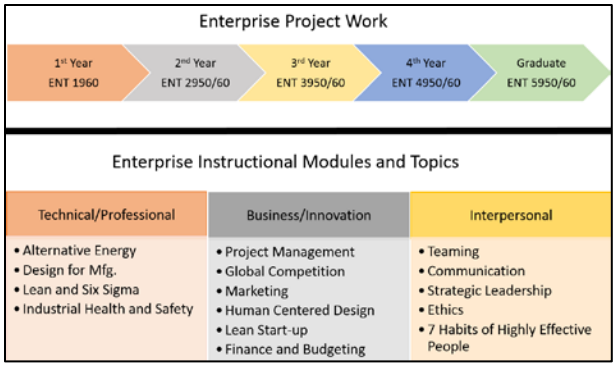

Figure 1: Enterprise project work and instructional modules

Administratively, Enterprise is housed in the Pavlis Honors College (PHC) and includes a faculty director, two dedicated program staff, and three part-time administrative staff. More than 30 faculty and staff from multiple academic units outside the PHC provide advising and instructional support. As a project-based curriculum that relies heavily on external financial support, program staff secure sponsored projects using a per-project fee of $15-17.5k. Projects can be conducted either as unrestricted donations or as restricted projects providing sponsors a path to acquire intellectual property, if developed. Annually, more than $650k in external support sustains and grows the program; about 75% of enterprise teams have external support at a given time. In addition to industry-sponsored projects, many teams conduct entrepreneurial and internally-supported projects, much like a company with a mix of client-sponsored and internal R&D efforts.

Program enrollment and the team portfolio have grown steadily. In the first year of operation, 11 enterprises were created with 200 students from 19 disciplines. Today, approximately 800 students from 30+ disciplines are enrolled in 25 different enterprises.

Accreditation and assessment

Enterprise was designed from the outset to provide engineering majors an optional pathway to complete their capstone design project. As such, it must provide students a comparable design experience to the engineering departments' capstone courses, which are linked to multiple student outcomes associated with ABET accreditation. Per ABET Criterion 3, an accredited program must have documented student outcomes (a-k) that prepare students to attain the program educational objectives[2].

During scale-up, inherent challenges with assessment and accreditation resulted from the program's interdisciplinary structure. For instance, several enterprises were advised by faculty from non-engineering departments such as computer science, technology, humanities, and business. Additionally, the advisors from engineering often had students from other disciplines on their teams. Another challenge involved instances where senior engineering students were leading and managing, but not designing and building. In 2009 a sub-committee comprised of engineering and enterprise faculty determined that project work completed by students in ENT4950/4960 would be used for ABET assessment. This would ensure consistency in providing a culminating design experience per ABET Criterion 5 (c). Further, the project work would be assessed using a subset of the ABET Criterion 3 student outcomes:

- c. (design)
- d. (multidisciplinary teams)
- e. (engineering problem solving)
- g. (effective communication)
- k. (techniques, skills, tools for engineering practice)

Assessment of ENT4950/4960 projects begins with approval of the student's project proposal. Both the enterprise faculty advisor and a faculty representative from the student's degree-granting department must approve the proposal prior to enrollment in ENT4950. If the proposal does not meet the minimum ABET criteria outlined above, revisions must be resubmitted. Once approved, both the faculty advisor and academic department sign a form indicating which ABET student outcomes the project will address, upon completion. This form and the approved project proposal are maintained for program assessment.

To assess the achievement of ABET student outcomes, a design rubric is completed by enterprise faculty advisors at the completion of ENT4960. This rubric is used to evaluate an individual student's performance on the project relative to the ABET student outcomes defined above. Advisors are brought together each semester to ensure consistency in understanding the ABET criteria and applying the rubrics. All final project reports are collected and maintained for assessment. In addition to faculty advisor assessment of individual students, a similar project-level design rubric is completed by sponsors upon project completion. The data collected from these rubrics are used to assess sponsor/team interactions and sponsor perceptions of student work as it relates to the ABET student outcomes. Finally, the annual Design Expo event provides a third source of assessment data, where team posters and presentations are evaluated by a panel of judges comprised of faculty, staff, industry sponsors, and other guests. To date Enterprise has been involved in three review cycles of all ABET-accredited engineering and technology programs at Michigan Tech.

Multi/Inter-disciplinary design

A national survey of capstone programs conducted in 2015 shows that multidisciplinary programs like Enterprise remain fairly unique, comprising only 6% of respondents (n=522 respondents from 256 institutions).[3] In contrast to the traditional department-centric capstone program, Enterprise can be viewed more like a corporation with a diverse portfolio of businesses or divisions, each aligned around a specific industry sector, business, or technology focus. Each team's composition aligns with the needs of that given sector. Sectors currently served by enterprises include: communications, environment, technology, human health & interface, electronics, robotics, materials & manufacturing, and vehicle design & transportation. Each of these sectors requires the knowledge of multiple and specific disciplines in order to successfully complete a project. With successful recruiting efforts, many enterprises are able to go beyond the engineering aspects of product, process, or materials development to address marketing plans, product feasibility studies, and financial analyses. Such collaboration requires students to learn to communicate across disciplines and to varying audiences. It also prepares students to frame and address multi-faceted, complex, real-world problems. By design, members of an enterprise team all have an equal responsibility in ensuring the completion of interdisciplinary project work.

When securing industry-sponsored projects, many of Michigan Tech's industry partners and recruiters often note that a particular benefit of the Enterprise Program is the opportunity to observe potential future employees over multiple semesters and in an organizational setting much like they will see post-graduation. This approach also allows for more complex and industry-relevant projects to be conducted by student teams. Long time program sponsor ArcelorMittal states "[Enterprise] has really helped us reach out to not only graduating seniors but also helped us get to know the underclassmen where we can watch them grow as Michigan Tech faculty and staff get to see."[5]

'*More than capstone*'

While Enterprise provides an option to the traditional capstone project experience, the multi-year and multi/inter-disciplinary structure make it much more than a multidisciplinary capstone program. Enterprise enrollment for the Fall 2017 semester included 708 students on 25 teams, with the following composition: 32% seniors, 41% juniors, 24% sophomores, 2% graduate students, and 1% freshman. Enrollment by school / college included 75% engineering, 17% sciences and arts, 5% technology, and 3% from business and economics. For reference, Michigan Tech's profile across these schools/colleges is 64%, 21%, 4.6%, and 5%, respectively.[5]

One feature of the Enterprise model is the ability of students to progress through their organization and develop skills over a longer timeframe than the traditional two-semester capstone project. Younger, less-experienced students start at "entry-level" positions taking on a variety of less-critical project tasks that help to build confidence and a successful onboarding experience. As students progress through course and project work, they can advance into roles with larger responsibility, allowing for further development of problem solving, project management, and leadership skills. As an example, *Blue Marble Security* is a 45-student enterprise whose mission is to "secure the future through thoughtful use of technology" applied to security, the environment, and industrial process control. The team's organizational chart includes: a President; four Vice Presidents covering Operations, Communications, Finance, and Public Relations; a Lab Manager; nine Project Managers for each of the team's projects; and multiple staff members assigned to each project. Project staffing is managed entirely by the student leadership, with input from team members and a review by faculty advisors to ensure the composition supports the project scope. In many cases, these leadership positions are held by engineering seniors also working on their capstone projects. The leadership responsibilities do not replace capstone but rather can serve to enhance student development by providing additional responsibility and professional development.

Two benefits of the multi-year approach are the ability to work on multiple projects and the potential to work on larger multi-year projects. The former provides valuable experience leading up to the capstone project. The latter exposes students to issues such as knowledge transfer, turnover, and staffing management. In a traditional capstone course, multi-year projects involve complete turnover of the students and rely on faculty advisors and written reports for knowledge transfer. In Enterprise, a portion of the student team can be retained from year to year. This promotes student ownership of knowledge transfer and retention, providing valuable mentoring and communication opportunities between upper- and under-class students on the teams.

Program successes, enhancements, and next steps

Enterprise's 18-year track record includes several outcomes that document its value, including:

1. Third-year retention rates averaged 96.4% for Enterprise students and 83.3% for non-Enterprise engineering students, based on four-year averages for engineering and technology majors matriculating 2009-12.

2. Graduation rates for Enterprise students were 94.6% and 74.3% for non-Enterprise students, based on two-year averages for engineering and technology majors graduating 2014-2015.
3. Enterprise students make up about 14% of the undergraduate student body but account for 30% of invention disclosures filed by undergraduates.
4. Enterprise has been the recipient of national recognition as an innovative and exemplary project-based program. [6]

In 2011, Raber et al. published the results of an Educational and Career Impacts Survey completed by students enrolled in Enterprise and Senior Capstone Design, comparing student perceptions of program impact on educational outcomes.[7] As compared with students completing the traditional capstone design experience, senior-level students in Enterprise more strongly agreed (with statistical significance at $p<0.05$) that their involvement in the program contributed to their outcomes in teamwork, communication skills, and career preparation. Furthermore, Enterprise students attributed their faculty advisor and interaction with teammates as contributing most to these outcomes, likely due to the relationships that are established over a multi-year timeframe.

Over the years, Enterprise has been incrementally modified to what is now a mature educational model with stable enrollment. This begs the question - what's next? In 2015, strategic visioning sessions with key stakeholders identified several goals for shaping *Enterprise 2.0*. The first goal is to facilitate learning across the program, through cross-enterprise collaborations and collaborative projects across two or more enterprises. Recent efforts in support of this include the re-launch of the Enterprise Student Advisory Board and industry support for a new Enterprise Manufacturing Initiative. Another strategic goal is to increase enrollment in underrepresented disciplines and complement the current enterprise portfolio through the creation of new teams in interdisciplinary fields such as forest biomaterials, transportation / civil infrastructure, and data science. A third goal is to develop a more comprehensive assessment to capture the valuable learning not explicitly defined by the ABET outcomes (e.g. leadership, mentorship, innovation, and entrepreneurship).

Lastly, one untapped source of valuable assessment data is the Program's alumni. The Enterprise Program Office recently released a survey to over 3,000 alumni which aims to evaluate the impact of the Enterprise Program, as well as other aspects of the graduate's educational experience, on post-graduation success and skillset development. To date, over 300 respondents have provided feedback. The data will be analyzed and published during the 2018 calendar year to identify key strengths and opportunities for program improvement.

Conclusion

Enterprise is Michigan Tech's answer to industry's need for graduates who possess a well-rounded skill set obtained through experiential learning in a unique multi-year, interdisciplinary, team-based environment. Enterprise is open to all majors, and engineering majors can use it to fulfill departmental senior capstone design requirements. An established assessment plan ensures capstone equivalency per ABET student outcomes. Enterprise provides students ownership of a portion of their education that connects strongly with their personal and professional goals. As compared with Senior Design, Enterprise enrollment is linked with higher retention and graduation rates as well as higher student perceptions of the program's impact on their professional skills. Since 2000, Enterprise has grown steadily to include 800 students/year and is financially self-sustaining through external support from industrial partners and donors. While the program model has matured over time, recent efforts are underway to continue evolving Enterprise to leverage cross-program learning, expand in new interdisciplinary areas, and broaden assessment.

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