A Decade of Multidisciplinary Capstone Collaboration

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This paper describes an ongoing effort to increase the number of students engaged in multidisciplinary capstone projects at Ohio Northern University, which began a decade ago as an initiative involving the efforts of a handful of faculty. Over time, the number of multidisciplinary-related projects has grown such that approximately half of the senior-level students from two engineering departments are involved. Improvements designed to engage more students both within and outside of the College of Engineering are discussed. The paper describes the evolution of this collaborative program, and provides some lessons learned for those who are attempting to bring more multidisciplinary experiences to their students.

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Introduction

In 1996, ABET adopted the *Engineering Criteria 2000* (*Criteria*), a new set of standards that changed the focus of accreditation from what is taught to what is learned.[1] Amongst the *Criteria* were specifications of "an ability to function on multidisciplinary teams" as one of the 11 student outcomes common to all engineering programs, and that students are "prepared for engineering practice through a curriculum culminating in a major design experience".[2] While not required by ABET, many programs have combined these two specifications through the development of multidisciplinary capstone design experiences as an ideal way to implement these requirements.[3] In a national study conducted in 2001, 88% of the respondents reported that their capstone students were organized into teams, and 47% reported that at least some project teams were comprised of multiple disciplines.[4] Some efforts, such as at Harvey Mudd College[5] and the Colorado School of Mines[6], well predate the establishment of the *Criteria*; however, it was also quickly recognized that there is no consensus model for implementing a multidisciplinary design experience.[7] It should be noted that the definition of what constitutes a multidisciplinary team has proven to be quite malleable across institutions and even across programs within a single institution.[8] Definitions range from involving different specializations from within an engineering major, to involving different engineering majors, to involving majors from both inside and outside of the engineering profession. For the purposes of this paper, "multidisciplinary" shall refer to teams that contain members from two or more distinct engineering departments, each of which house one or more engineering degree programs.

Literature Survey

Comparing the results of a 1994 survey of capstone courses[9] with results from a similar but expanded survey[10] in 2005, the authors of the latter work noted a substantial increase in interdepartmental teams over the intervening decade. The initial survey indicated that 21% of respondents participated in interdepartmental capstone design courses, whereas a decade later this was true for 35% of respondents. This suggests that departments are intentionally increasing opportunities for cross-disciplinary collaboration. The same survey also indicated an increase in the variety and total number of departments participating in interdepartmental capstone courses. The authors pointed in particular to the surge of computer engineering and computer science collaboration, reflecting the growing dependence on, and integration of, computers in engineering design.

Multidisciplinary capstone programs are administered in different ways. Some multidisciplinary courses are optional programs administrated outside of an engineering department. At the University of Florida, mechanical engineering students have the option of a one-semester capstone entitled Mechanical System Design, or they may take a two-semester Integrated Product & Process Design track (IPPD).[11] The former is a standard mechanically-oriented design project course run within the Mechanical Engineering department whereas the IPPD program is an independent educational initiative tackling industry projects with small teams of students from among nine engineering departments and the business school.[12] The case is similar at Carnegie Mellon, where an extradepartmental entity called The Institute for Complex Engineered Systems offers an interdisciplinary team-based product design course open

to junior, senior, and graduate level students from the colleges of engineering, computer science, fine arts, business, humanities, and science.[13] Projects are one-semester in scope, but the course may be taken for up to two semesters. Though team composition varies, a "typical team may have three engineers from different departments (perhaps two undergraduates and a graduate student), an undergraduate industrial design student, and a graduate student in the English Department's Professional Writing program."[14] However, unlike Florida, Carnegie Mellon engineers cannot use this course to satisfy the capstone requirement, which varies by department. The University of Tennessee at Chattanooga requires a two-semester interdisciplinary design project (IDP) for all engineering students.[15] For several engineering majors this sequence also serves as a discipline-specific capstone whereas for other majors, such as electrical engineering,[16] students must complete both the IDP and an additional one-semester capstone course. At Marquette University,[17] most capstone teams are multidisciplinary, though the projects are not designated as such with a distinct course number. Each Marquette engineering program has its own capstone course in the catalog, though all share the same course number; multidisciplinary teams are given a single departmental designation primarily for administrative convenience.

Multidisciplinary at Ohio Northern University

Ohio Northern University (ONU) has an enrollment of approximately 3300 students across five colleges. The engineering college is divided into three departments: Civil Engineering (CE), Electrical & Computer Engineering and Computer Science (ECCS), and Mechanical Engineering (ME). Within each department, capstone has been organized as a year-long sequence of courses, with the focus in both the ME and ECCS departments being placed on both the design and the prototyping of a product. ONU's first experience with multidisciplinary capstone teams occurred in the 2003-2004 academic year, with four projects made up of students from the ME and ECCS departments.[18-19]

Since that initial effort, significant changes have occurred in the ONU engineering capstone program: some related specifically to the effort to make projects more multidisciplinary, and some related to the curriculum of all capstone projects. The most significant change from a scheduling point of view is that ONU switched from a quarter-based to a semester-based academic calendar. This provided the opportunity to significantly change the capstone calendar as well. Based partly on the prior work by two ECCS faculty members for promoting engineering management standards within capstone courses,[20] a common set of due dates and assignments was jointly developed by the two departments. First, the projects are assigned, and teams are then formed, in the spring of the students' junior year. This allows teams to begin doing research on their project over the summer, and "hit the ground running" when they arrive for their senior year. To facilitate this, the two departments' capstone coordinators work together in the spring to decide which projects are appropriate for multidisciplinary teams and how many students are needed for such projects. The common set of assignments between the ECCS and ME departments allows students participating in multidisciplinary projects to avoid having to complete separate, yet similar, assignments for each department. All teams take part in multiple Project Review Boards, which provide feedback throughout the design process, and present their results to an outside audience at a design showcase held in the spring. Additionally, assessment rubrics have been made common for all assignments completed by the students. Through these processes, the multidisciplinary projects have become an established part of the process, rather than just one-time efforts based on individual faculty initiatives. Finally, some other changes in the College of Engineering have had an impact on this initiative. Like most colleges, the numbers of students in different programs have shifted significantly in the last decade. When this initiative began, the college had 46 ECCS seniors and 35 ME seniors (an unusually large ME class at that time). Currently there are 23 ECCS seniors and 39 ME seniors (which is now a typical class). Recently, CS students have had the option of either taking their own capstone courses or participating with engineering majors on a multidisciplinary project. The College of Engineering has also added a new major in engineering education, and these students are embedded within multidisciplinary projects for their capstone experience.

Efforts have been undertaken in the past to broaden the multidisciplinary experience by also having business students involved with engineering capstone projects. These efforts have been much less consistent, formally consisting of four projects over the past ten years. The College of Business Administration at ONU has a typical business capstone requirement consisting of a one-semester strategy course. In several cases, some students from the business college have chosen to work with an engineering capstone project. However, the different expectations (in terms of both deliverables and credit hours) of the capstones of each college, combined with scheduling challenges and lack of strong team formation, have led to problems with each of these projects.

Despite the aforementioned changes, some things have remained the same. ONU still believes in a mix of capstone projects, combining design competitions, industry-sponsored projects, and undergraduate research.

Not all students will participate in multidisciplinary projects, and Civil Engineering has had limited involvement in multidisciplinary projects at ONU. The courses, and the responsibility for evaluation and grading, still reside in the individual departments.

Benefits and Challenges of ONU's Approach

Involving students from multiple disciplines on a capstone project has many benefits, not the least of which is a higher fidelity version of real-world engineering. It is hard to find a design project in industry which truly involves only one engineering discipline, and students in nominally single discipline projects will still require the application of knowledge from outside their area. Additionally, while it is good for students to be stretched to employ the skills at the periphery of their major (e.g., circuit design for mechanical engineers), the reality in industry is that the bulk of these tasks will generally be done by those more comfortable with the tasks.

Students in multidisciplinary teams have often been able to divide design and prototyping skills by specialty. This has enabled them to take on projects of greater complexity. A wider array of modern technology is accessible when the strengths of multiple engineering disciplines are available. For example, one team of ONU mechanical, electrical, and computer engineers successfully designed and built a spherical, remotely video-piloted robot[21] which would have been very challenging for students of any one of those disciplines to develop alone. Another such team completed a remote control amphibious charging pad for quadrotors. These multidisciplinary projects also taught students how to communicate and negotiate design requirements and tradeoffs with those in other disciplines. Engineers in industry must routinely communicate with those in other engineering disciplines or departments as well as the accountants and the business managers. Additionally, those projects which were chosen for partnership with business capstone groups gained invaluable experience answering questions vital to the financial viability of their design: proposed cost, potential market, sales projections and strategy, and time to develop the initial prototype into a market-ready product.

With the benefits of multidisciplinary projects also came some challenges, primarily organizational in nature. First, no common capstone class time currently exists across any of the programs; while this does allow maximum class-scheduling flexibility for both students and faculty, scheduling a common group meeting time is significantly more difficult when students and faculty from multiple departments are involved. Another challenge is that differences still remain regarding departmental expectations for capstone teams. These differences force the ME and ECCS capstone coordinators to decide for each multidisciplinary group which department's syllabus and ancillary requirements that the group will abide by. As a further complication, both the ME and ECCS departments have a lecture component to their capstone courses which adds both individual- and team-based design process assignments. Finally, while common rubrics are used, grading policies and expectations still vary between the two departments and need to be reconciled on a case-by-case basis.

Envisioning a Multidisciplinary Future

Engineers must be adept at clearly communicating to, and understanding the communication of, other disciplines. Accordingly, the use of multidisciplinary capstone projects provides students with a more realistic exposure to the processes of design and prototype construction that are found in industry. Though internal and external obstacles still remain, the efforts to integrate senior capstone projects across the Ohio Northern campus have proven worthwhile, and sometimes exemplarily so.

To arrive at a multidisciplinary-oriented future, clarification is first needed as to what "multidisciplinary" means as applied to Criterion 3(d), and to its importance from an engineering perspective relative to the whole of the criterion: "an ability to function on multidisciplinary teams." Most of the literature related to this criterion has focused on the professional skills associated with teamwork. There has been less discussion amongst the greater engineering educational community and their respective professional organizations regarding what should properly constitute the minimum scope involved for the label of multidisciplinary to be valid, or to what extent do the associated professional skills need to be embedded within the curriculum in order to satisfy ABET requirements.

To better promote a fulfilling experience for our students, additional efforts are needed to fully integrate multidisciplinary teams to the greatest extent possible. Ways in which this can be done include, but are not limited to, the following items listed in descending order of importance:

- Creating a common core of capstone-related material, including deliverables, that is covered in all associated curricula via a common schedule. This does not necessarily have to be entirely within the capstone project coursework itself; there are programs that have successfully developed multiyear capstone experiences where the concepts are learned in earlier coursework, and then applied while being reinforced within the actual capstone course(s). Separate recitation meetings could be

added for dealing with issues and concepts specific to a particular discipline.

- Scheduling a common "capstone laboratory" time across all curricula to ensure that all students, including those on multidisciplinary teams, are guaranteed a regular time slot for weekly meetings. Faculty advisor schedules could also be similarly designed to guarantee their availability during such time slots to their teams.
- Examining ways that modern communications technologies, such as teleconferencing and cloud computing, can be leveraged to allow consortiums of like-minded engineering colleges to form multidisciplinary teams consisting of students from multiple institutions.
- Creating courses tailored to serving students engaged in multidisciplinary capstone projects.
- Identifying a client to serve as a single external point of contact to both provide direction to the project and for promoting business-appropriate communication skills.

As Ohio Northern's engineering college continues to make strides in improving the capstone experience for its students, the authors welcome inquiries regarding potential collaboration on any of these items.

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