AC 2009-2282: INTEGRATING REAL-WORLD EXPERIENCE INTO A COLLEGE CURRICULUM USING A MULTIDISCIPLINARY DESIGN MINOR

Jessica Brakora, University of Michigan

Brian Gilchrist, University of Michigan

James Holloway, University of Michigan

Nilton Renno, University of Michigan

Steven Skerlos, University of Michigan

Toby Teory, University of Michigan

Peter Washabaugh, University of Michigan

Daryl Weinert, University of Michigan

Integrating Real-World Experience in to a College Curriculum Using a Multidisciplinary Design Minor

Abstract

The real world offers tremendous challenges and numerous opportunities for our engineering students after they complete their formal undergraduate education. Many of these challenges are intrinsically multidisciplinary and require work across the boundaries of traditional educational programs. Too often engineering programs fail to mirror this reality, but instead stovepipe student experiences along disciplinary boundaries (often excluding non-engineers entirely) and fail to provide the touchstone of reality that comes from actually implementing a design.

Many of us have seen or been involved with successes of students working in teams to accomplish sophisticated design challenges. Some examples from the University of Michigan include developing small spacecraft, water filtration techniques for remote villages using indigenous resources, the design and fabrication of a solar car to race for thousands of miles across North America and Australia, developing an aid to alleviate a physical impairment, or tools and resources for non-profit organizations. These and other activities engage students in significant multi-semester technical and organizational efforts that create tremendously valuable experiences and that send them out in the world both wiser and better leaders at levels not possible by "book learning" alone. The challenge this presents is how to effectively integrate the multidisciplinary design-build-test experience, with traditional educational programs.

The University of Michigan College of Engineering is addressing this challenge by implementing a new minor in multidisciplinary design (MD Minor). This initiative is intended to curricularize and expand the impact of our successful design team activities that have historically operated largely independently of the classroom. It is one part of a broader initiative to create exciting opportunities for our students that also includes strong co-curricular programs in entrepreneurial and international experiences. The goal we strive for is to have our students graduate with significant experiences that better prepare them for professional life in a multidisciplinary world. Here, we give a status report of our efforts to implement the MD Minor.

Details of the MD Minor include the following requirements: (1) an introductory design-build-test (DBT) activity, (2) a cornerstone course that serves to prepare the student in depth for his or her multi-semester design project, (3) a multi-semester, multidisciplinary DBT project, and (4) involvement in mentorship and/or leadership experiences. In total, there are 15 credit hours required to earn the MD Minor. The reasons for these specific requirements and our experiences in fitting this into the curriculum at Michigan's College of Engineering will be presented.

Introduction

Our engineering profession is finding increasing pressure to respond to urgent societal challenges of significant complexity in a world of increasing population, decreasing natural resources, and ever growing concerns for environmental sustainability. Add to this, the growing availability of increasingly sophisticated technologies for design problems both simple and complex. Preparing our undergraduates for a world of professional practice must contend therefore with educating students with technical knowledge that is growing rapidly while simultaneously preparing them to address ever complex, interdependent problems.

A recently published study conducted by the Carnegie Foundation for the Advancement Teaching[1] looked at 6 American engineering schools and noted a continuing and widespread emphasis on textbook-centric theory over hands-on practice, an approach that discourages many students and largely leaves them unprepared for real-world problems. Summarizing this study, The Chronicle of Higher Education[2] noted that warnings of these concerns have been sounded for more than 20 years. It is not our purpose here to speculate on the reasons for this situation. Rather, we will describe some of Michigan's efforts to provide a growing number of students with exciting and meaningful multidisciplinary hands-on design-build-test project experiences which we hope will prepare them for the challenging engineering problems of the 21st century and help motivate their fundamental classroom-gained knowledge.

Our experience suggests that engineering students arrive at their school typically excited about doing engineering and design and hopeful about their potential future impact. Yet they often have very little basis to understand what that really means, or to comprehend the connection between their classroom knowledge and professional practice. Important pressures also exist for our industrial "customers" who must be able to respond to the need for increasingly sophisticated problem solutions, requiring more sophisticated skills in professional practice from our graduates. Given this "moving target" in needs, if we are not able to more completely prepare our students, there will be a delay between the time of graduation and the time when our graduates can be fully effective innovators.

In the Carnegie Foundation's summary of their study on engineering education[3], part of their findings included the following:

> "The central lesson that emerged from the study is the imperative of teaching for professional practice — with *practice* understood as the complex, creative, responsible, contextually grounded activities that define the work of engineers at its best; and *professional* understood to describe those who can be entrusted with responsible judgment in the application of their expertise for the good of those they serve.
>
> "If engineering students are to be prepared to meet the challenges of today and tomorrow, the center of their education should be professional practice, integrating technical knowledge and skills of practice through a consistent focus on developing the identity and commitment of the professional engineer. Teaching for professional practice should be the touchstone for future choices about both curriculum content and pedagogical strategies in undergraduate engineering education."

The central vision of Michigan's new Minor in Multidisciplinary Design resonates well with this finding. There certainly are others who have made similar arguments to refocus and reintroduce practice in to the curriculum[4] and for more active or problem-based learning that is closely aligned as well.[5] It can be also noted that experiential learning has been adopted as the core of professional education in other professions such as medicine, law, and business.[6]

Although a "work in progress," we are focusing on addressing the broader needs of professional practice while hopefully motivating and improving core classroom knowledge education. We are tracking the following as some of our most important principles:

1. The real-world is multidisciplinary and our skills of practice must cut across engineering disciplines and even extend beyond engineering;
2. Engineering development must include at a minimum early project scoping (definition of requirements/constraints), concept design, building, and testing – we refer to this simply as the design-build-test (DBT) process.
3. This cannot be simply a traditional capstone, one-semester, senior-level, activity – students should be engaged as early as practical, ideally in the first year, and be able experience the DBT cycle more than once with growing sophistication.

Because the MD Minor is new we are not able to report on rigorous or detailed studies of its implementation, but we can report that we have extensive inputs from employers who are strongly in favor of seeing students acquire these experiences with their strong engineering science foundation. Employers tell us that if they had to choose between a student who had classroom-only instruction or a student with design project experience as well, the latter would be preferred. Similarly, there is a sense that there would be a preference for a student who has worked on an original, external real-world problem as opposed to one who has worked on a classroom derived capstone semester experience because of the expectation for better realism.

Building on What is Working

We have found numerous examples of on-going (sustainable) student-led DBT projects that have successfully attracted and integrated multidisciplinary groups of students to work on real-world projects spanning ones focused on societal needs (which we call "design for the greater good", Figure 1), competitions, as well as research and development. We know that there must be corresponding examples at many universities. These projects inherently include many of the features that we believe are important in training for engineering professional practice as described above.

Figure 1. Design for the Greater Good *Students working in developing communities testing alternative designs of appropriate drinking water sanitation technologies*

An example of a student competition project is Michigan's solar car race team (Figure 2), which has won five national championships in the North American Solar Challenge. This race covers thousands of miles every two or three years, and involves students from many engineering and non-engineering disciplines throughout the process.

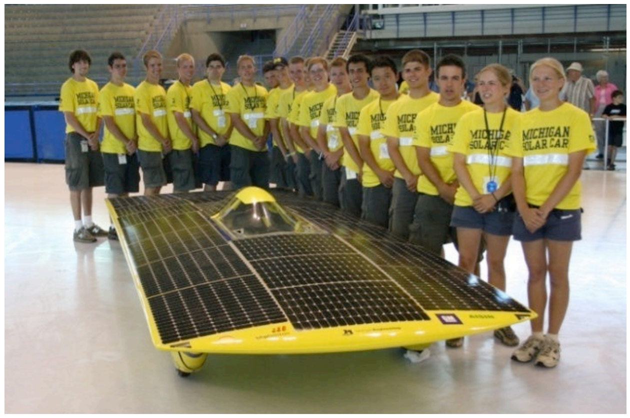

Figure 2. Solar Car Team *Students from multiple disciplines including engineering, business, art, and liberal arts have created a long-running successful organization*

We have had students engaged for nearly a decade in the Student Space Systems Fabrication Laboratory, successfully self-managing themselves with the oversight of faculty advisors. Students work on projects that they identify, are part of faculty research, or competitions.[7,8,9] One example is shown in Figure 3, which shows a small satellite built by students for NASA and mentored by faculty and engineers from Michigan's Space Physics Research Laboratory (SPRL). The Icarus spacecraft had a mass of 21.3 kg, was battery and solar-cell powered with an average power requirement of 12.5 W. It was equipped with a magnetometer and GPS receiver to measure the dynamics of the spacecraft system.

Figure 3. Icarus *Students in the Space Systems Fabrication Lab have created an extracurricular program to build spaceflight-qualified hardware*

Another recent example from S3FL is shown in Figure 4. One of our PhD students, Mr. Tom Liu, defined a set of top-level goals and measurements and has mentored an undergraduate team of students who developed an experiment to fly on NASA's C9 microgravity experiment. Mr. Liu is using the data as part of his PhD research.

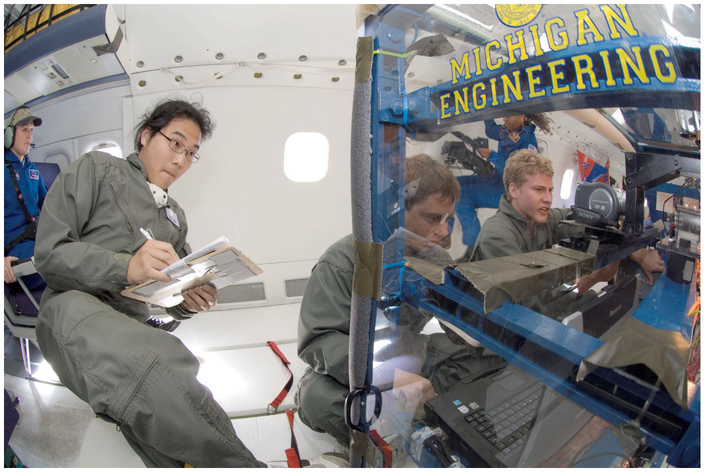

Figure 4. Microgravity Project *An undergraduate team has built an instrument system to support doctoral research*

In all of these projects, the student team is multidisciplinary and engages students for typically two or three years. An exciting feature of most of these projects is the feedback loop that develops between upper-level students mentoring and training their younger colleagues. In effect upper-level students are training underclassmen in a variety of technical and fabrication techniques, thereby creating an organically grown curriculum that is effectively parallel to formal classes. These training and mentoring activities are essential components of the projects and are needed to make first year students full fledged members of the team.

An important result has been that students who spend a good fraction of time (e.g., 3 years or more out of a typical 4-year program) participating in these design-build-test projects graduated with a wisdom far beyond their years. They not only had knowledge, but they knew how to apply it appropriately. Our very best students have participated in these activities and then graduated as colleagues with B.S. degrees.

Program Description

In our Minor in Multidisciplinary Design, we have tried to build on the successes of our self-organized student teams. The minor has four core elements outlined in Figure 5.

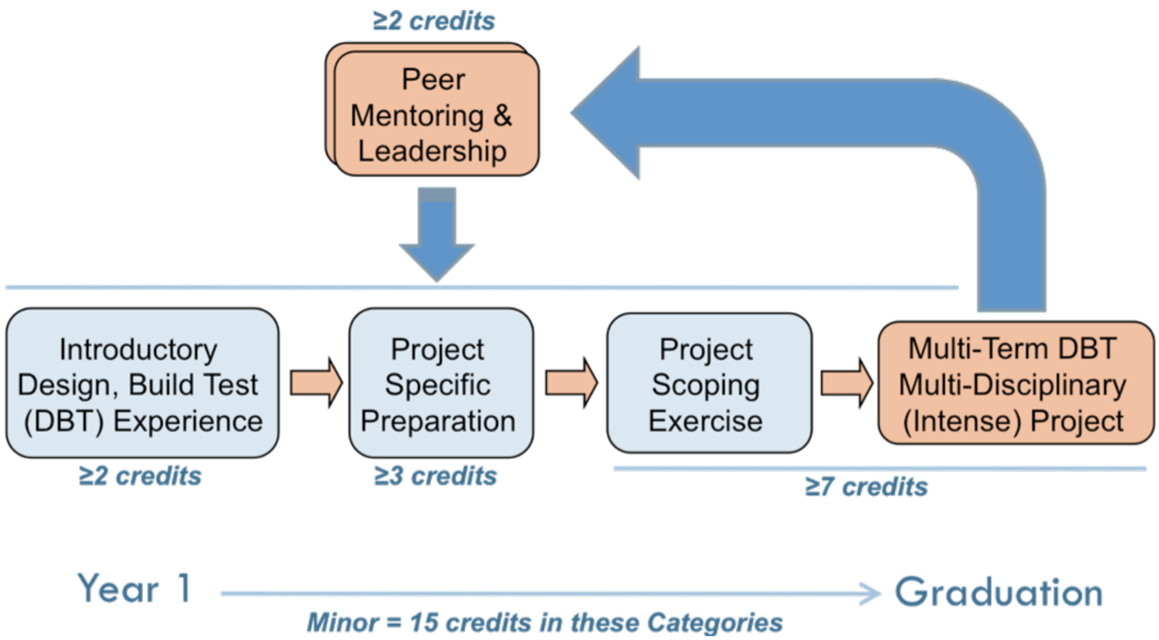

Figure 5. MD Minor Template *A multi-year experience*

1. Introductory DBT requirement: The introductory Design, Build, Test requirement is meant to give students their first immersion experience in a small engineering team project. This is where students first learn what it is like to go through the whole DBT process but on a smaller scale. This is most usefully done in the Freshman or Sophomore year.
2. A preparatory course requirement: Students are required to take a "cornerstone" course that serves to prepare them in depth for the multi-term major design, build, test, requirement. This requirement is to be taken outside of the student's major department and required major course work.
3. Major DBT requirement: The major design, build, test requirement is a multi-term, multidisciplinary project that gives students the opportunity to 1) identify the problem through qualitative and/ or quantitative requirements, 2) generate creative solution concepts, 3) analyze the quality of proposed concepts, 4) select and optimize the final concept, 5) evaluate the final concept through the building and testing of prototypes or virtual models, and 6) iterate and/or detail recommendations for improvement of the final concept based on the lessons learned from the previous steps.
4. Mentorship and/or Leadership requirement: The leadership/mentorship requirement of this program is to help encourage and to pass on knowledge to less experienced design project team members, as well as to reinforce learned abilities in the senior team members. In addition, it provides the human resources to allow the DBT teams to grow and sustain themselves for many years without faculty having to provide all of the mentoring of team members.

One of the principal considerations in the development of the Minor in Multidisciplinary Design was harnessing the enthusiasm of faculty and students to tackle new and exciting design challenges. Our implementation committee brainstormed numerous approaches that could potentially engage new populations of faculty and students. It was thought that by allowing for the creation of specializations within the minor, new programs could evolve - bringing new faculty and students into the program around topics of current interest. Therefore the program was designed to allow sponsoring faculty within the College of Engineering to develop their own specialization for the minor, each with its own requirements, as long as the umbrella requirements of the Minor in Multidisciplinary Design were met.

Specializations that have been discussed so far include Space Systems, Global Health, Sustainable Energy, and Service Learning. A student completing the requirements for a specialization within the Minor in Multidisciplinary Design can elect to have this specialization reflected on his or her transcript (e.g., "Minor in Multidisciplinary Design with Specialization in Global Health Design"). While these specializations can be tailored to the passions of specific faculty groups and students, an umbrella Minor in Multidisciplinary Design also exists so that being a part of a specialization is not required to receive a Minor in Multidisciplinary Design.

Some of the expected advantages associated with allowing for specializations in the program included the following:

1. Students participate in a design focus that is recognized on their transcript while gaining expertise that might aid in gaining future employment or grad school admission in a related area.

2. Faculty can develop a pool of students around a specific topic related to their research interests while getting this investment in student education institutionally recognized through the transcript designation of the specialization.

3. The existence of specializations creates the potential for the program of minors to grow more sustainably and in larger increments than might be possible with ad hoc projects - since the specializations themselves are required to last at least four years and are linked directly to faculty interests in their specific areas of expertise.

4. Departments and the college can benefit through the evolution and creation of new programs of high visibility and interest to future students and the general public.

5. Departments and the college have an additional vehicle to create and bring visibility to programs that link engineering to departments across the university.

One particularly innovative example of a specialization is in the area of Global Health, which brings together the medical and engineering disciplines, along with the social sciences. In the Global Health Specialization, students actively participate in a two-semester design program while being exposed to the specific needs of global health both before and during the intense design period. The Global Health Design (GHD) Specialization emphasizes field experience, cultural sensitivity training, exposure to global health issues and a medically-themed design course. As a result the expectation is that they will continue to cultivate these issues throughout their career, generating a new mindset within both the technology developer communities and the medical community that uses technology. A key feature of the GHD program is immersion within a community where global health issues are prominent, leading to a problem formulation and specification process that is then the target of the two-semester design sequence. Students are expected to return to the field site well before the end of their program so that direct feedback on the design can be acquired and included within a major design iteration.

Providing an example from a typical engineering student perspective, a biomedical engineering student pursuing a minor in Multidisciplinary Design with Specialization in Global Health might work on the design of a disposable device for point of care diagnostics that can be used in developing countries. The idea could be to develop a device that is low cost, low power, not dependent on refrigeration, and easy to use. Naturally such a project lies at the intersection of biomedical engineering and global health where the student might work with medical professionals, anthropologists, mechanical engineers, industrial and operations engineers, and community leaders.

Summary

We are introducing a Minor in Multidisciplinary Design (MD) with a strong emphasis on the special learning that comes from experiencing the design-build-test cycle. A key design principle for the minor has been to build off what we see as successful practices of many of our long-running self-organized student teams, while simultaneously providing a curricular structure so that students can have their Design-Build-Test (DBT) activities recognized within their formal educational experience. These principles include providing an introductory DBT experience, because it is important to experience the DBT cycle more than once. Equally, having experience students mentor and train more junior students provides both the human resource to involve many students, provides the educational rewards of teaching to the mentors. The minor design recognizes the key importance of having a broad, diverse team not only design, but also build and test their design.

We are in the process of declaring our first students and graduating some that have already fulfilled the requirements through their work on ongoing team projects. Specializations such as Space Systems, Global Health, Sustainable Energy, and Service Learning are currently being finalized. With the approval of these specializations, we are anticipating a large number of students to be part of the Multidisciplinary Design Minor experience. We are also now developing the methods for which we can more quantitatively study the impact and outcome of this program for our students.

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