AC 2011-2472: MAKING A COLLEGE-LEVEL MULTIDISCIPLINARY DESIGN PROGRAM EFFECTIVE AND UNDERSTANDING THE OUTCOMES

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Making a College-Level Multidisciplinary Design Program Effective and Understanding the Outcomes

abstract

The University of Michigan's College of Engineering (CoE) has committed to a significant Multidisciplinary Design (MD) Program complementing the bachelor degree programs. This enables students from across degree programs and even outside of the CoE to collaborate on projects. This is currently being done by flexibly addressing instructional and practicum needs through a series of short seminars, semester and multi-semester long project work, and a minor. Participation by students varies from ½ day events up to and including the full academic minor. We are developing and evaluating ways to track performance of the program, students, and graduates. We recently completed an initial study of students who were currently engaged in or previously engaged in multidisciplinary design team experiences outside of the classroom. This type of experience is central to the MD minor, thus our work targeted a better understanding of the nature of students' work and the outcomes of their work with respect to their own development. Further work has begun to study questions centered on students' experience of practicing creativity within the program. Our next steps include transferring lessons learned into broader curricula of our bachelor degree programs, connecting with masters-level programs, reach for more students, and incorporating more disciplines in our programming.

introduction

Shephard et al.'s work [4] emphasized "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." Additional reports emphasize the need for professional practice; Duderstadt [1] claimed "… it is long past time that we ripped engineering education out of the lecture hall and place it instead in the discovery environment of the laboratory, the design studio, or the experiential environment of practice." Addressing this need and helping to define a path forward in determining how we should educate in the 21st Century differently than was done in the 20th Century represents an over arching goal for the MD Program.

As an institution with strong emphasis on research, large student populations, and a graduate to undergraduate student ratio of approximately 1:2, this engineering program must address two important challenges: (1) scalability: the CoE currently enrolls nearly 5500 undergraduate students, and (2) breadth of programs: the CoE currently offers 15 academic bachelor degrees. The Multidisciplinary Design Program has as a core a belief that excellence in engineering requires creativity and that the entire engineering process is essentially a creative one that utilizes highly refined technical skills as its building blocks. The MD Program combines students from a range of disciplines to work on significant, creative, real world multidisciplinary design projects that include design, build and test (DBT) elements.

Below, we both describe the Multidisciplinary Design (MD) Program and share some initial evaluations of the educational benefits for students and graduates who have entered the work force.

multidisciplinary design program

To focus on the creative engineering design process in a multidisciplinary world, the CoE Multidisciplinary Design (MD) Program was formally created in 2009. It has as its goals:

- To support the needs of students to prepare for a multidisciplinary world with a program that:
    - Addresses professional practice ("learning to be") through an experiential process of creative engineering in a multidisciplinary environment;
    - Promotes a broad spectrum of high quality experiential, multidisciplinary DBT opportunities that is sustainable and that engages other schools/colleges at Michigan as well as outside partners from industry, government, and other appropriate organizations;
    - Motivates and deepens the understanding of classroom acquired knowledge along with laying the foundation for the skills to be life-long learners.

- To *curricularize* these activities for the benefit of our students and to work with departments and schools to integrate open-ended, multidisciplinary creative engineering experiences into their curricula.

In developing the new Multidisciplinary Design Program, we have been able to draw upon numerous examples of student-led DBT projects already in place that have successfully attracted and integrated multidisciplinary groups of students to work on real-world projects. These span activities focused on societal needs, a wide range of competitions, and even research and development. Specific examples include student teams developing and implementing cleaner cooking fuel technology for villages in Nicaragua, genetically engineering new bio-systems, designing and racing sophisticated solar cars (leading to 6 national championships since 1990), as well as building and flying nano-satellites in space or in a NASA microgravity aircraft. Many universities will have similar examples. These projects inherently include many of the features that we believe are important in the education of engineers for professional practice as described above.

The MD Program provides students the opportunity to acquire design skills as well as to experience "creativity during engineering" through multidisciplinary project work. A range of participation levels are available from single ½ day seminars up to the completion of the 15 credit academic minor in multidisciplinary design. Programming includes seminars in leadership, communication, project management, how to effectively manage a design review, developing useful user specifications, CAD design, as well as many other skills. The focus is on open-ended engineering challenges and successful multidisciplinary teamwork.

Student design projects can be self generated, part of clubs, part of engineering competition teams, sponsored by industry/government labs or even faculty research efforts. At the moment our program has examples of all five types of projects, a sampling of which includes: (1) self generated group: creating toys for sight impaired children; (2) EcoLab club: building water purification equipment for Brazil and biogas fermentation units for deployment in India; (3) Solar Car competition team: building power storage units; (4) Capstone design courses provided by industry and (5) Students participating faculty research: creating new thin film conducting materials. The complete design, build, test cycle requires significant effort and thus the minimum participation level for actual project work is one semester; more typically students participate in project teams for 12 to 18 months. Single semester experiences are most typically limited to capstone design courses.

Students with the highest participation level will complete the Multidisciplinary Design Minor, which consists of a series of creative engineering opportunities of increasing complexity Most colleges (Liberal Arts, Business, Art & Design) within the university allow the engineering college based minor. This broad base of participation enhances the experience of working and problem solving across diverse groups for our multidisciplinary design students. The minor is organized in to four required elements. These are summarized in Figure 1.

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 degree 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 students (the same project or other student design projects including for example high school or middle school projects) as well as to reinforce learned abilities in the senior team members. In addition, it provides possible human resources to allow the DBT teams to grow and sustain themselves over the years without faculty needing to provide all of the mentoring of team members.

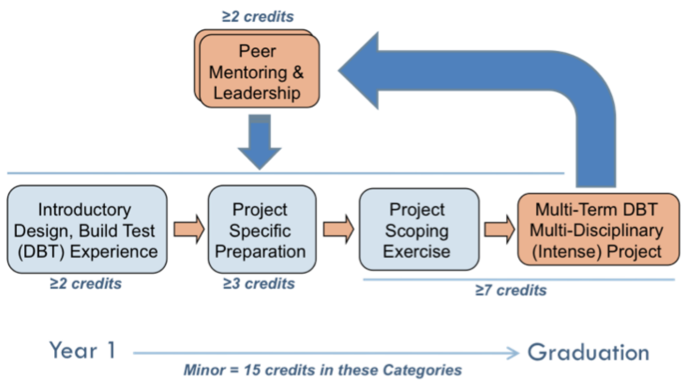

Figure 1: *MD Minor template. A multi-year experience.*

While in some ways the MD Minor can be thought of as the heart of the Multidisciplinary Design Program, we do not expect every undergraduate will or even should earn this minor. However, a goal of working with departments of the College of Engineering to integrate multidisciplinary and DBT experiences broadly in the undergraduate curriculum drives our overall efforts. For example, the College of Engineering, working with departments, has actively promoted the creation of sections of our required introductory freshman course (ENG 100, serving some 1,300 students each academic year) that have hands-on DBT activities . Students who take these sections automatically meet the first requirement of the MD Minor.

implementation challenges

In the process of delivering an effective program we have encountered a number of challenges including: mentoring and support, generating projects to match with student interest, departmental degree policies that constrain the multidisciplinary nature of the projects, and space within the curriculum.

(1) Mentoring and Support

Although all projects are student lead and organized, participation of mentors (faculty, alumni, or volunteers) is necessary. Faculty members provide valuable feedback and advice throughout the process, especially during design reviews. At this university, faculty compensation and day-to-day support is distributed through departments. Departments provide different levels of commitment and support in the form of teaching buy-outs, material support, travel support and laboratory space. The commitment to support a student project can be difficult, especially for highly time constrained faculty, and this problem is especially acute for non-tenured faculty. The MD Program seeks to support faculty by directly supporting students with advising and by working with departments to find creative solutions to these challenges. We have begun to include alumni and local professional volunteers as mentors within the program to expand the number of mentors and the specialized skill set available, helping both the students and faculty. As with faculty, inclusion of a mentor requires matching not only skills and availability but also compatibility with the students.

(2) Matching portfolio of projects to student interest

At the present time we have approximately 275 students active in the program from across the University. Roughly a quarter of them are pursuing the minor, and thus will require projects. As mentioned before, projects can come from a number of different sources (sponsored research, clubs, competition teams, faculty research, etc.). With a quickly growing program it can be difficult to correctly estimate and then help generate student project opportunities to match with student demand. This is made more difficult as students may elect to participate in their design, build, test project any time during sophomore, junior, or senior year. Soliciting projects and funding is not sufficient. We need to have projects in areas of student interest. We also intend to use a broader choice of projects offered to aide in the recruitment of more diverse student participation. Thus, we are encouraging *specializations* within the minor to attract students and faculty around topics of current interest. Current or developing specializations include topics such as Global Health, Sustainable Energy, Service Learning, Space Systems, and Campanology (with the Schools of Music and Art & Design). We hope particularly to attract and retain more women and underrepresented minorities into our program.

(3) Degree specific constraints

All engineering students participate in a capstone design course where often they are allowed to generate their own project idea. Many of the MD Program students would like to incorporate their capstone design course into their longer Design, Build, Test project. Frequently this is not viewed as possible because of restrictions in specific capstone design course requirements to meet graduation accreditation requirements. This is made more complicated when disciplinary knowledge content is integrated in to the capstone design course. In order to facilitate multidisciplinary project teams some University of Michigan faculty have initiated co-teaching / co-registration of courses. That is, two separate course numbers, separate registrations, and separate grading but combined faculty instruction and project teams. We think this is a positive approach to this challenge.

(4) Time/space within the curriculum

Finally, within the curriculum there is simply a limit to the number of requirements that can be incorporated within a 4-year program, and this presents a barrier to students seeking to do something extra like the MD Program. Although we would like to see all students participate in a full design, build, test experience there realistically isn't time. Developing a range of opportunities allows students to more easily fit MD Program experiences into their degree program.

initial evaluation of the md program approach

We are seeking objective means of evaluating the student learning experience in the MD Program to allow us to refine and improve the experience. We have started with studies of small numbers of students using constant comparative methods[3] to highlight some of the strengths and weaknesses of the learning experience. These students are currently engaged in or were previously engaged in multidisciplinary design team experiences outside of the traditional classroom. This type of experience is central to the MD minor, thus our work targeted a better understanding of the nature of students' work and the outcomes of their work with respect to their own development. This work included in-depth interviews on how students processed through their projects, the ways they interacted with their teammates from different majors, how they conceptualized the act of designing, and what factors contributed to their growth as multidisciplinary designers.

The following are research questions we used in our initial study:

- How do students with multi-disciplinary design practice talk about their experiences?
  - What advantages do they perceive?
  - What challenges do they encounter?
- How do students' conceptions compare to novices and more advanced practitioners in school and industry? What areas would we want to support additional growth?
- How do students' conceptions inform a larger set of questions that could be used to investigate differences between students who have these types of experiences and those who do not?

research methods

participants

Participants were recruited from all undergraduate years involved in multi-disciplinary design teams as well as students that had graduated and started their careers, but participated in a multi-disciplinary design team while they were at the university. Students were contacted through email and asked if they were willing to be interviewed about their design team experiences.

Participant	Gender	Major	Current Status	Years Of Multidisciplinary Design Experience
P1	F	AOSS	3 years post-school	1 year experience
P2	M	ME	Senior	3 years experience
P3	F	Civil E	Junior	3 years experience
P4	F	AOSS	Senior	4 years experience
P5	M	AOSS	Senior	3 years experience
P6	F	AOSS	Master's	5 years experience
P7	M	AOSS	Senior	4 years experience

data collection

Qualitative semi-structured interview data served as the data informing this study. The interviews were grounded in students' design experiences. Thus, the beginning interview questions were about the details of the experience, and were followed by questions about the impacts on themselves they have seen from these experiences. This interview protocol design allows students to remember deeply about the experience and therefore, reflect more deeply about the impact of the experience, how they changed because of the experience, and how they view and approach interdisciplinary design in general. The interviews were audio recorded and lasted approximately one hour. An outline with example questions of the protocol is included below.

Focus of Questions	Example Questions
General Information	• What is/ was your major? • What are you doing now?
Describing the Multi-disciplinary Design Experience	• What project(s) did you work on? • Can you describe a particular experience on that project where you where you worked multi-disciplinarily? • How did you approach working with others with different disciplinary backgrounds and perspectives? • What about your approach was successful? What challenges did you face?
Describing the Design- Build-Test Experience	• Can you tell me about an experience you had that involved design that was taken through a build-test process that you considered to be personally and professionally successful?

	• How did you approach the task? • What skills and knowledge do you need to have to be a good designer?
Impact	• How balanced was your work with other responsibilities as a student? • How did your MD experience impact your view of coursework? • How did your MD experience impact your job search, preparation, and professional activities?
Summing Up Ideas	• What was the most important experience you had as part of your MD team? Why? • Are there things about your experience that you feel were not beneficial? • If you could do it all over again, how would you change your involvement? • Reflecting back, what was the value of the experience?

data analysis

Interviews were transcribed and analyzed for themes using a constant comparative approach ((Lincoln & Guba, 1985). During analysis, we looked for similarities and differences between students' ideas, approaches, and impacts of the experiences.

results

Below we highlight some key findings from our interviews and include some sample excerpts from participants.

Participants reported a broader understanding of the design experience from beginning to end. They recognized that the first design outcome is not necessarily the "end of the design, and they could learn something from the first attempt to improve their designs:

> *The nice thing about balloons is you design it, and you work on it, and then you can actually fly it, and so you can see how it works. And then when you get it back, you can figure out okay, what went wrong. How do we make it better next time? So the whole process of design, build, test-fly's a lot quicker. And so then I feel like it also makes it more rewarding because you can see the fruits of your labor.*

Failure existed in all of the students' multidisciplinary design experiences. The opportunity to fail in these contexts supported participants' awareness or the reality of failure, and transforming failure into learning opportunities, in design work.

> *Sometimes, you are gonna have to fail. We knew what was wrong. It's not like we weren't gonna be able to fix it remotely. It's just we didn't have the equipment there with us, so it's learning to be resourceful in areas where you don't have everything with you or you didn't plan certain things to happen…Sometimes, yeah, things will run a lot*

smoother if it's structured, but will the students be getting the same experience? Probably not. Will some of them fail? Yes. But again, like I said before, they'll learn a lot from failure because we're all gonna fail at some point, and you need to be able to handle that and then move forward and keep working.

The necessity of learning from other disciplines was evident to participants as a result of their MD experiences. They were challenged to cross-disciplinary boundaries and recognized the importance of improving at these skills.

The controls, the straight just mechanics of the controls, is very sound for mechanical, but then the hydrodynamics and that interaction is just – I sometimes am at a loss to get my head around that. But you have to tie them together, and then the mechanics of the controls of the naval isn't nearly as straightforward, so there's always that boundary of the interaction that makes things interesting. But that's pretty much where engineering's going these days, so if you can get good at that, you can get good at everything else.

The time and context provided participants with the opportunity to attempt to create a working design with multiple attempts, whereas in the constraints of classes, this is often a limiting factor. They explained testing and iteration as an important aspect of a successful design strategy.

The most important thing for that project specifically was just testing, so kind of the whole process of design building and then you're testing it and then it's failing and so you redesign it and rebuild it. So the testing was the most important thing because, you know, if we had only designed it once and not tested it and built one of them and not tested it, it would have failed on a flight, so the iterative process really helped.

Participants had a high self-efficacy about their ability to succeed in their future multidisciplinary design work. This was a result both of the increased knowledge and skills associated with their experiences as well as having had an authentic experience with real outcomes and hurdles:

So I think it's really gonna serve me well once I get out of college and say, hey, I worked on this multidisciplinary project four years in a row, and I think it's gonna really lay the groundwork for me to be able to work on actual job sites and communicate with people from different backgrounds and stuff like that.

Participants struggled with having to make difficult decisions on their own and while they felt that could have benefits for their future, desired additional mentorship:

I wish there was more direction from the top, so – especially in my position right now, so it's – I'm in a difficult position because I feel like I'm kinda giving directions to everybody and I'm getting the funding and I'm doing all the scheduling and it's very rare that I have somebody ask me from the top if I need any help with anything. So maybe a little more direction, like one-on-one direction, especially in the leadership role. Something like that might be helpful… It would be nice just to get some sort of feedback *as well, so right now I just make decisions and kind of roll with them and I don't get good or bad feedback. I just – everything seems to be working fine, but I would like to get more feedback from the top about my position. So I'm getting feedback from my team members and they're giving me feedback, but I'd like to know how I'm doing from people above me."*

It was evident that students had not reflected on many of their experiences on a deeper level until they were asked to unpack their conceptions as part of the interview. Participants were even aware that they struggled to be specific in regards to what the learning outcomes were. For example:

> *I know it's all really vague, but whenever you're involved in something from a higher level, basically, the answer is yes, you're learning stuff. I can't necessarily tell you what exactly it is, but it's kind of like when people say, "Oh, you learn so much from traveling," and people ask you what, and you can't explain what it is. It's kind of like that.*

Additional Program Evaluation

Besides the initial interviews described above we have run two short focus groups with juniors and seniors from across the college of engineering to better understand how they relate to the engineering experience in general. Specifically we probed the way in which students described the process of engineering design, the profession of engineering, and the question "what is required for engineering excellence?" The students generally described the process of engineering design and the profession of engineering as "scientific" and "technical". There was even a clear rejection of the labels "creative" and "creativity" to describe required elements of engineering excellence. These results are highly preliminary, based on a small sample and are in the process of being reviewed and validated.

discussion

The objective of the Multidisciplinary Design Program is to enhance and improve the student learning experience of the engineering process, especially as practiced within multidisciplinary teams. In evaluating our students' personal project experience we discovered that students were so immersed in the details of their projects that many of them did not take the time or know they should take the time to think about their approaches and processes on a higher, meta-cognitive level. The interviews were the first time that many of the students had thought about what they learned and how their experiences informed their strategies for future multidisciplinary design work. While the interviews served as our means for data collection, they also provided a guided way for students to reflect on the project with which they have been involved through the MD program.

In the future we are looking to foster this type of reflection for all students. Kolb's model[2] of experiential learning (Figure 2) provides a foundation for how to maximize learning from experiences. This model reflected in the MD program would include guided reflection opportunities (perhaps in the context of a one-credit seminar course) after students have had some time immersed in an MD experience and as they continue in those type of experiences. Reflection opportunities will allow students to process their learning and strategize how to improve their approaches to their work. They can practice these strategies in their experiences and use the guided reflection and feedback from faculty, mentors, and even fellow students to help their success.

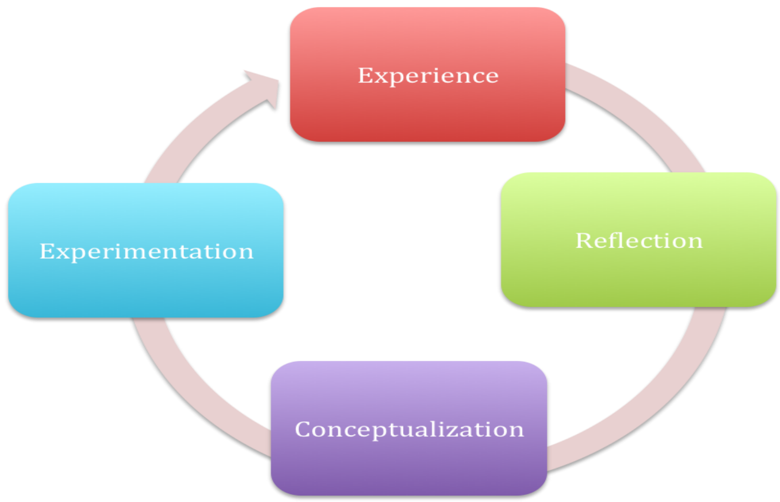

Figure 2. Kolb's (1984) model of experiential learning

conclusions

The initial evaluation efforts of the Multidisciplinary Design Program at Midwestern University yielded important results that help us continue to shape our program. Students have opportunities to be immersed in real-world experiences in which they can adopt a systems perspective to their work, engage in multiple design-build-test cycles, and increase their awareness of other disciplinary perspectives. To help students get the most out of these experiences, we have learned that we need to better support their reflection on their experiences and the translation of that reflection to lessons and strategies that can employ in their continued work.

In addition to improving the program's curricula, our next steps focus on broadening and increasing disciplinary diversity in participation. This effort to broaden diverse participation may also provide an opportunity to help students understand what creativity means in the context of engineering and how they can apply creativity skills to increase their potential for innovative solutions.

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