Annual Report on the College of Engineering’s Multi-Disciplinary Design Study

By
Durward K. Sobek II
Boeing Professor
College of Engineering
Montana State University
Bozeman, MT  59717

August, 2006

Executive Summary

For the past year, I have led an assessment of MSU College of Engineering’s multi-disciplinary program. Interactions with the College’s design faculty strongly indicate that attempting to incorporate multi-disciplinary design into the senior capstone experience is not appropriate for our College given the highly differentiated needs and capstone objectives of the individual programs. In consultation with a cross-disciplinary advisory team, a set of proposed objectives were established, which include an ability to: view engineering projects from a systems perspectives; recognize trade-offs across disciplinary perspectives; communicate technical and other trade-off information across disciplinary boundaries and negotiate satisfactory resolution; and generate creative, integrated and effective solutions collaboratively.

The advisory team also evaluated a number of alternatives, which resulted in a short-list of four. Additional conversations with a broader set of College faculty, including department heads, further reduced the set to two top alternatives:

1. Create a College-wide junior level design course to teach basic design skills to all COE students in the context of a multi-disciplinary project, as a prerequisite to the senior capstone.

2. Offer a suite of multi-disciplinary design electives, where project-based courses would cluster groups of disciplines that frequently work together in industry; students would take one course from the set.

The next steps are to present the alternatives to the entire College community through the annual faculty retreats, and from this feedback, request a recommendation from the
College curriculum committee. Pending a timely decision, a pilot course is targeted for Spring 2007.

Background

Montana State University has a long and rich tradition of engineering education excellence. Our graduates are sought after for their solid grounding in engineering fundamentals and strong technical skills. Part of that tradition is a capstone design experience within each program in the senior year. Each program has evolved its own senior design course over the years to suit its particular curricular needs. Typically projects have been team-based with representation from within the discipline exclusively.

A few years ago, the College of Engineering recognized an opportunity to enhance the student educational experience by offering a multi-disciplinary design opportunity for the senior design project. In Fall of 2002, under the direction of Dr. John Sears, the College initiated the “No Walls” program whereby students could take ENGR 401 or 402 as a substitute for their discipline’s capstone course(s). The basic premise was to put together teams with appropriate disciplines as dictated by the project requirements, and recruit students (largely through the capstone instructors) to enroll in a multi-disciplinary design course. Dr. Sears would then recruit advisors for the projects from the disciplines represented (thus teams had 2, 3 or more advisors), and negotiate project deliverables for the team sufficient to satisfy the requirements of the students’ home capstone course requirements. In the first year, a handful of projects were tackled in this fashion with some success, so in the subsequent year the program was scaled up to increase the number of projects and students participating.

However, in the Fall of 2003, Dr. Sears abruptly left the university. Drs. Vic Cundy and Mike Wells, the mechanical engineering capstone instructors, were asked to serve as co-coordinators of the “No Walls” program. Over the next two years, the ENGR 401/402 fell into disuse as the overhead of coordinating a large number of projects became overwhelming, especially since Drs. Cundy and Wells were coordinating the program as an additional burden on their already significant teaching loads. Every project was unique, with unique team composition and advisory structure. The specific requirements for each project were negotiated each semester between the respective capstone instructors, advisors, and students. This was a time consuming and often confusing process. Many students felt they had significantly more requirements placed on them than their classmates working on single-discipline teams, even though they were enrolled in the same course. And while some projects were spectacularly successful, many where not. In fact, in exit interviews, many graduating seniors cited multi-disciplinary design as their worst College experience.

Therefore, in Fall of 2005, Dean Marley requested me to conduct a study, with Dr. Carolyn Plumb’s assistance, to determine a best path forward with respect to multi-disciplinary engineering. During the course of the study, the current “No Walls” program has been suspended pending the results of the study. This report summarizes the activities and findings of the study to date, starting with the research.
Groundwork Investigation

Before diving into solutions, Dr. Plumb and I conducted an investigation into multi-disciplinary programs at other institutions, defining what problem we’re really trying to address, and understanding the current state of design instruction within the College.

Other Multi-disciplinary Design Courses

As a first step, Dr. Plumb and I searched the engineering education literature for programs and courses on multi-disciplinary design. We also identified a number of engineering colleges through personal contacts and web search that claim a multi-disciplinary design program, and interviewed the directors. From this background work, we learned that about half of all engineering colleges in the US claim to have some sort of multi-disciplinary design program, a trend that seems to be increasing. However, it appears that every program is unique. We were not able to identify a model for the structure of multi-disciplinary design programs. We concluded that successful multi-disciplinary design programs are uniquely designed for the culture and environment of the particular institution. We would not likely be successful by copying and tweaking a program from another institution. This work, though, turned up a number of ideas that we could possibly leverage for MSU.

Curricular Tabulations

In parallel, I accumulated the individual program requirements for all of the engineering and technology programs within the College. This analysis revealed that while many programs take courses common to other programs, there is no single engineering course that all COE students take (all students take calculus, general physics, freshman composition, and communication; but these are outside the College and with the rest of the university).

There are also a number of “majors only” course offerings on topics that students from other programs take. For example:

<table>
<thead>
<tr>
<th>Course</th>
<th>Major(s)</th>
<th>Non-major(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introductory Circuits</td>
<td>EE206 for ECE majors</td>
<td>EE250 for non-majors</td>
</tr>
<tr>
<td>Introductory Statistics</td>
<td>I&amp;ME 354 for IE majors</td>
<td>I&amp;ME 350 for non-majors</td>
</tr>
<tr>
<td>Fluids</td>
<td>ChBE 322 for ChBE majors</td>
<td>EM 355 for CE, ME (elective for EE, IE)</td>
</tr>
<tr>
<td>Introductory Thermodynamics</td>
<td>ME 320 for ME majors</td>
<td>ME 324 for non-majors</td>
</tr>
<tr>
<td></td>
<td>ChBE 322 for ChBE majors</td>
<td></td>
</tr>
</tbody>
</table>

Thus students in Industrial Engineering, for example, never get the chance to interact with other engineering disciplines on a topic germane to their home discipline. Some of these courses are potential opportunities to introduce multi-disciplinary elements.
All programs except ME and the technology programs have a course in professionalism or ethics, usually 1-2 credits. All programs save CET and CS have an introductory course to introduce students to the major and recruit them.

**Design Instructor Interviews**
The next step in our investigation on the landscape of design education within the College was to interview all of the design instructors in the College. Most of the programs have only one 3- or 4-credit course (or equivalent number of credits in a course sequence) in design, and it is the capstone course. ME has an introductory design course that is a prerequisite to the capstone, while MET’s capstone sequence is 6 credits across two courses. Thus, *most students graduate from the College with only one beginning-to-end design experience*—their capstone project.

We confirmed that the number of credits, course structure, course requirements, and course content differ significantly across programs. This was often cited as the reason that the current “multi-D” program was not more successful. However, we learned from the interviews that these differences derive from very different, and legitimate, differences in the pedagogical objectives. For example, ME and EE capstone objectives focus on the design of a device, from defining customer needs through design and analysis to producing a paper and/or prototype design. CE capstone objectives, on the other hand, focus heavily on project procurement, project management, and construction drawings and specifications. The “design process” presented to CE students bears little resemblance to that taught to ME students. ChBE and IE programs are different still, since they focus on process design with economic analysis playing a central role. Thus, the capstone courses in each program have been designed to meet specific curricular needs of each program. It may be possible to align the objectives of each of the capstone courses, but this would involve modifying significant portions of each curriculum, a major undertaking with uncertain outcomes. Thus, *we concluded that attempting a college-wide multi-disciplinary design experience in the capstone is simply not appropriate or desirable.*

The capstone courses do share some common objectives. Particularly, all focus on working effectively on teams, oral and written communication, design process, and project management. However, the amount of formal instruction and direct intervention varies widely across the College for several of these objectives (e.g., project management), and is uniformly low on at least one (teamwork). Also, creativity is not heavily emphasized in any of the design courses.

Every design course instructor saw value in a multi-disciplinary design experience. However, they varied in how valuable they saw it, with some claiming it was critically important, and others saying it would be nice, but not as important as other educational objectives.

**Advisory Board Interviews**
I interviewed the Mechanical & Industrial Engineering departmental advisory board and about 8 members of the College’s Engineering Advisory Council about what they envision of multi-disciplinary design. Responses were far from uniform, with at least one
person indicating that the value of multi-disciplinary design at the undergraduate level was unclear. The themes that came out from the interviews were:

- “Multi-disciplinary” means different things to different people. To some people, it means two or three engineering disciplines working together. To others, it means taking manufacturing considerations into account. To still others it means including non-engineering disciplines such as business, marketing, and industrial design.

- It’s important for graduates to be able recognize trade-offs that occur across traditional disciplinary boundaries. They must be able to take a “systems perspective” of the projects on which they work.

- They must be able to appreciate differences in the perspectives of others.

Industrial advisory board members indicated that a multi-disciplinary experience need not occur in the capstone, so long as students graduated with these skills. When pressed on the relative importance of these multi-disciplinary engineering skills, the consensus seemed to be that they were important, but not as important as technical skills.

**Development of Objectives and Alternatives**

To develop a set of proposed objectives and a set of alternatives for a future multi-disciplinary design program within the College of Engineering at MSU, I assembled a ten-member cross-disciplinary team that included representatives from ChBE, CE, CS, ECE, ME, MET and the Dean’s Office. I served as the IE representative. CET was not represented.

From the groundwork investigation, I developed an initial set of objectives for the multi-disciplinary program, whatever shape it may take. These objectives were presented to the advisory team, and were refined through several iterations.

The proposed objectives of the College’s multi-disciplinary initiative are to build in our graduates the capacity to:

- View engineering projects from a systems perspective.
- Recognize and appreciate trade-offs across disciplinary perspectives.
- Communicate technical and other trade-offs, and negotiate satisfactory resolution.
- Generate creative, integrated and effective solutions collaboratively.

Also from the initial groundwork, in collaboration with the advisory team, we generated 8 alternative approaches to accomplish the above objectives, not including combinations. As a team, we evaluated each alternative against the following criteria:
1. Ability to meet multi-D objectives
2. Complementary to curricular objectives of participating programs
3. Ability to achieve good fit between project needs and disciplines represented
4. Ability to achieve consistency in expectations/requirements of students
5. Implementation and support cost (actual $)
6. Reasonable faculty load (e.g., faculty hours required per student)
7. Acceptance among COE faculty
8. Space needs

From the set of eight, four alternatives were selected to carry forward. Briefly, these alternatives were:

- A hands-on Freshman course that exposes students to “how things work” from a multi-disciplinary perspective.
- Revamped engineering fundamentals courses that present fundamental concepts from a multi-disciplinary perspective.
- A junior-level multi-disciplinary design course.
- A suite of multi-disciplinary design electives, each clustered around natural groupings of disciplines (engineering and non-engineering) that commonly interact in practice.

I then began conversations with a broader group of faculty to (a) give them the background and rationale for where we are going to hopefully build some consensus, and (b) to obtain their feedback on the set of alternatives. I met with the department heads, 5 IE, 4 ME, 3 ChBE faculty members, and 1 CE, 1 CS, and 1 CE faculty member in addition to the advisory team (in most cases, the discipline’s advisory team representative was also present in the meetings). From these conversations, two of the alternatives emerged as clear favorites; however, there was not a strong consensus as to which of the top two would be preferred. The top two alternatives are described in the following subsections.

**Alternative 1: Junior-level Design Course**

This alternative is to implement a required junior-level design course for all COE students, similar to ME 403 or CHBE 310. The course would introduce students to design topics such as design process, creative design, project management, and teamwork while highlighting the skills needed to work in a multi-disciplinary environment.

---

1 I sent out a much broader invitation, but did not get a good response from ECE, CE, or CET faculty. Hence, I would like to have engaged with more of my colleagues, but only a few were willing to carve out the time to meet with me.
Students would also complete a multi-disciplinary group project as a major component of the course. Other topics could possibly be incorporated, such as ethics and communication skills.

The course would become a prerequisite to the capstone courses in each program. Thus the instructor would need to coordinate with the capstone instructors, in essence treating them as customers, in designing and refining the course.

Multi-disciplinary design content would be incorporated into appropriate lecture topics throughout the course. Each semester could have its own theme for the design project, such as energy conservation, assistive technology for the elderly or impaired, or economic development for the third world. The instructor would have to make the team assignments to ensure multiple disciplines are represented on each team. The teams would then choose their own project within the semester’s theme. It may be possible to have a panel of judges evaluate the projects.

Given the scale of the class, most likely the course would require a lecture + recitation format. Lectures would meet twice a week in a large lecture hall; recitations would meet once a week in smaller groups of 20-25. Significant TA support would be needed.

---

**Benefits**

- Multi-disciplinary objectives can be made primary in the course.
- Would reach all students.
- A common College-wide experience.
- Capstone instructors can leverage or build upon course topics covered.
- Same requirements for all students.
- Practice run on a significant design project.

**Challenges**

- Finding the credits in each program (possible solution: return the “extra core” credits to the programs).
- Cost – would require a full-time instructor plus 2-3 TA’s.
- Making the course relevant to all disciplines.
- Convincing COE faculty of the merits of the course sufficient to add it as a requirement.
- Teaching a large project course (on the order of 200/semester enrollment).

---

**Alternative 2: Suite of Design Electives**

With this alternative approach, the College would develop and offer design elective courses under the ENGR rubric designed around natural clusters of disciplines. The clusters can be modeled after the kinds of disciplines that typically work together in industry. For example:

- Integrated product/process design: ME, EE, IE, Business
- Design-Build in Construction: CE, CET, Architecture
Humans would take the course as a professional elective, not as a substitute for the capstone (although, perhaps, some disciplines may allow a substitution). The courses would be project-based. Most of the courses would require some technical content be taught through lectures, depending on the nature of the course. Throughout each, the multi-disciplinary design objectives would be emphasized.

As an implementation path, we would most likely develop and offer 1-2 courses per year. After 3-4 years, having tested, refined and proven the courses, we could make multi-disciplinary design “required” (i.e., every student takes one design elective) if the courses prove successful.

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi-disciplinary objectives can be made primary in the courses.</td>
<td>Finding course instructors.</td>
</tr>
<tr>
<td>Natural clusters of disciplines that mimic actual work environments.</td>
<td>Freeing up or funding additional instructional resources.</td>
</tr>
<tr>
<td>Clear paths for incorporating disciplines from outside COE.</td>
<td>Getting students to enroll initially.</td>
</tr>
<tr>
<td>Flexible: can offer as many different topics as we like.</td>
<td>Getting courses approved as professional electives in different programs.</td>
</tr>
<tr>
<td>Fresh and creative: can incorporate new course themes as they arise in industry.</td>
<td></td>
</tr>
<tr>
<td>Potential conduit for instructional creativity.</td>
<td></td>
</tr>
<tr>
<td>Easily incorporated into degree programs as an elective.</td>
<td></td>
</tr>
</tbody>
</table>

**Faculty Response**

As might be expected, responses of College faculty members range widely from enthusiastically supportive to strongly opposed. On average, the climate appears to be mildly positive.

Some of the concerns raised were:
• While multi-disciplinary design would be a good thing to have, the curriculum is already filled to capacity with things that are more important for undergraduates.

• Some claim their program already has multi-disciplinary experiences in their program without having to go out of the department (for example, a structural engineer, soils engineer, and environmental engineer on one project).

• Others claim that even though the program does not explicitly include multi-disciplinary design experiences, graduates are nonetheless well-prepared to work productivity on multi-disciplinary teams because of a strong emphasis on general teamwork skills.

• We do not have good assessment data on how well COE graduates are meeting the objectives with the current curricula—how do we know that we need to change?

Next Steps

In July 2006, Dean Marley, Chris Jenkins (M&IE Department Head), Brett Gunnik (CE Department Head), Heidi Sherrick, Carolyn Plumb, and myself participated in the Engineering Educators Leadership Institute sponsored by the National Academy of Engineering’s CASEE program. At that event, we developed the following timeline for implementation.

August 2006    Sobek presents the two top alternative strategies at department faculty retreats; solicits comment and buy-in.

September 2006 Marley charges the COE Curriculum Committee with recommending one of the alternatives along with any other recommendations for implementation.

October 2006   Curriculum Committee makes recommendation to Dean; Selection of alternative

Nov-Dec. 2006  Marley recruits an instructor; instructor develops pilot course, publicizes course, and recruits students

Spring 2007    Offer pilot course

Summer 2007   Assess pilot course, and decide future direction

Parallel with this timeline, Dr. Plumb and I will be working on how to assess outcomes related to the proposed objectives above.