Beyond Capstone Design – Developing a New Graduate Design Pedagogy and Program

Mark E. Rentschler and Jack L. Zable
University of Colorado

The mechanical engineering department at the University of Colorado has initiated a new design program for its graduate students. The core of this program is a three course sequence, Advanced Product Design, Graduate Design Projects 1 and Graduate Design Projects 2. The subject matter covered in the core courses was developed at multiple meetings held by the design faculty, members of the electrical engineering faculty and executives from industry who had extensive design experience. A broad range of product design related subjects and materials were suggested as subject matter for the core courses, and ranged from engineering economics to user-centered design to designing with ambiguity. Many of these subjects could be taught as a course within themselves. A rating system was established so that the most important materials related to product design were taught in these three core classes. A relatively large team of instructors were established to teach these three courses, with a few of the instructors coming from industry. The first course in the sequence, Advanced Product Design, was taught in the Spring of 2010. It is lecture based but with a team project theme associated with the course. The Graduate Design Projects courses will be first taught in the Fall of 2010 and Spring of 2011 semesters. While there will be some lectures in the graduate design projects course sequence, the focus will be on projects. The project teams established for this course will be interdisciplinary, with the projects coming from industry, the University of Colorado Denver Anschutz Medical Campus, and product ideas from the Advanced Product Design course. The immediate popularity of this Design Track program was exhibited with approximately 15% of the existing Master's degree graduate students registering for this program within three months of it being offered. Additionally, the enrollment in the Advanced Product Design class has exceeded its limit of 40 students.

Corresponding Author: Mark Rentschler, mark.rentschler@colorado.edu

Introduction

The University of Colorado's mechanical engineering department has a graduate program that currently consists of approximately 90 Master's students and 95 PhD students. The students in the Master's program must register for a subject or technology track in which they will major. This allows the students to attain a level of focus in an area of mechanical engineering. There are 9 such tracks that cover such disciplines as bio-medical, nano-technology, mechanics, heat transfer, fluids, etc. The tracks consist of required core courses (typically 4) all of which the students must take, optional core courses (typically 2-3) and students have some choice in this selection, and a broad range of optional courses. A thesis option is available to students in each track.

However, there was not a Design Track, in spite of the department's close and strong affiliations with many companies and government laboratories in the Boulder area. There also seemed to be a significant interest in design from potential graduate students who visited our department. On the negative side, the number of faculty in the department interested in a graduate design program was small. The latter has changed over the past two years as a result of new faculty hires. With these changes, strong interest from students, and support from the department and industry, it was decided to offer a Design Track for Master's degree students. It was hoped that it would attract a sufficient number of students to the department's graduate program and also establish the Design Track as a sustainable program. The establishing of a graduate design track also required the approval of the mechanical engineering department. Basically this entailed establishing an educational and resource justification plan. This was accomplished via the use of informal student surveys, obtaining design faculty commitments relative to teaching, and receiving promised support from many of our industry affiliates. Additionally an exit strategy was established in case of unforeseen and insurmountable problems.

Design Track Creation

There are six design faculty members within the department who decided to explore the creation of a Design Track program. They enlisted the support of four executives from industry and government who have extensive and current design experience. Additionally, electrical engineering faculty attended meetings to help determine the curricula for the Design

Track. This included the design and creation of three new core courses, and the determination of which existing courses should be used to complete the Design Track curriculum. Approximately seven meetings were held to discuss and formulate subject matter, new course materials, and the composition and definition of the courses. Discussions also took place relative to benchmark results of other programs, how to differentiate this program, how to obtain appropriate projects for Master's students, and interdisciplinary participation from the business school, other engineering departments and the University of Colorado Denver Anschutz Medical Campus. One key was to narrow down the broad range of subject matter into a core set that could be taught in three courses and still allow sufficient time for hands-on application of this material in projects. The development of this Design Track program took place over a span of two semesters.

Established Engineering Design Programs

There are several well established design-focused engineering programs in the United States. The Stanford Design Program run primarily through the Mechanical Engineering Department allows undergraduate students to major in Product Design, and graduate students to attain a Masters of Science in Design [1]. The undergraduate program teaches the design process with focus on creativity, craftsmanship, and emphasizes brainstorming and need-finding. The graduate program is a collaborative offering of the Department of Mechanical Engineering and the Department of Art and Art History. It provides students with a focus towards synthesizing technology, human need, business, cognitive science, and aesthetics.

Northwestern University has one of the most established tracks in engineering design. The Segal Design Institute, at Northwestern, offers a Master of Science in Engineering Design and Innovation [2]. The curriculum centers around a year-long course focus in Human-Centered Design Studio, Design Research, Differentiation by Design, and Sustainable Manufacturing. Elective courses include: Innovation Frontiers, Social and Knowledge Networks, Advanced Readings in Design, and Design Strategy. A thesis may be pursued during a second year of study at the student's choosing.

Portions from programs such as these were studied as we created our Design Track. However, in offering a Track instead of a full Program, led to challenges in developing a curriculum that provided depth while still exposing the students to a breadth of design areas.

Advanced Product Design

The subject matter selected for the three new core courses were limited by instruction time, faculty expertise, and its relevance in today's product development environment. The three course sequence consisted of courses entitled Advanced Product Design, Graduate Design Projects 1, and Graduate Design Projects 2.

The first course developed and offered in the Spring of 2010, Advanced Product Design, contains a very broad array of diverse subjects. These materials include; a description of the product development process going from customer needs to concept to product development to manufacture to product release and beyond, and the eleven requirements for having a successful product development cycle; including such factors as risk management, competitive analyses, management of key dependencies, and strategic alignment. Also included in the course is the determination of the required resources: people, money and time for product development, user-centered design concepts, determining the means for establishing product requirements, and the creation of product platforms for the creation of derivative products. Other areas covered are concept innovation and generation, TRIZ, advanced CAD, GD&T, and design for manufacture. Product aesthetics - basic concepts, aesthetic elements, and case studies were also presented. Engineering economics, which includes the time value of money, breakeven analyses, and the use of on-line tools were also taught. Sustainability issues such as life cycle design, minimizing resource consumption, environmental sustainability and estimating environmental impact were part of this class. Other topics covered were fast fabrication techniques, materials selection, compliance with industry and national standards, and designing with uncertainty. Examples were also given for the use of design curves to establish design windows.

The selection of this extensive list of subjects was determined by their perceived importance in product design in today's business environment. This was determined by a simple voting algorithm (very important, important, not too important), and subsequent discussions between the design faculty and the four industry representatives mentioned above.

Many of the subjects listed above are courses unto themselves and this presents time challenges, i.e. can all of this material be presented in an effective and meaningful manner in this one course. It was determined to use the two subsequent courses, Graduate Design Projects 1 and 2 as a safety net to teach those subjects mentioned above that required more instruction time. It is expected that this will be the case. Four permanent faculty members and an adjunct faculty member with successful, significant and recent product development expertise taught equal segments of the first course, Advanced Product Design. Each segment was 3 weeks (6 lectures) long. This class was limited to forty students and ten student teams were formed. Each team

selected a product idea or project upon which they would be involved for the entire semester. Each team was responsible for writing a short report (about ten pages) at the end of each of the five teaching segments. Each report discusses the application of the subject matter presented in each three week segment relative to their project/product. At the end of the semester each team consolidated their five reports into a final presentation given during the week of finals. In addition to these class deliverables there were individual homework assignments and on-line quizzes. The textbook for this class was created from segments of other textbooks, published papers, personal product development experiences, and other materials.

Topics covered in 3-week session (#1):

- Product Planning
- Product Platform
- Customer Needs
- User-centered Design

Topics covered in 3-week session (#2):

- Engineering Economics
- TRIZ
- Creativity and Innovation
- Concept Generation

Topics covered in 3-week session (#3):

- Aesthetics
- Design for Manufacturing
- Dimensioning and Tolerancing

Topics covered in 3-week session (#4):

- Fast Fabrication Techniques
- Prototyping and Manufacturing Processes
- Product Sustainability Design

Topics covered in 3-week session (#5):

- Product Development Process
- Material Selection
- Design Curves
- Designing with Uncertainty

Project examples from the first offering of Advanced Product Design included: Kids Headphones with Integrated MP3 Player, Deployable Wind Shear Array, Combined RFID/GPS Luggage Tracker, and the Design of a Bicycle for Overweight Users.

Graduate Design Projects

Advanced Product Design is a pre-requisite for students entering the Graduate Design Projects course. Graduate Design Projects 1 and Graduate Design Projects 2 are primarily hands-on project design classes. The projects will come from a variety of companies and government laboratories, the CU technology transfer office, the University of Colorado Denver Anschutz Medical Campus, entrepreneurship product ideas from students in the class in conjunction with MBA students (sponsored by grants), and non-profit organizations. These projects would differentiate themselves from capstone design projects by being more difficult (greater breadth, greater complexity, greater ambiguity, more undefined parameters, and more difficult analyses), having greater involvement with determining requirements, being interdisciplinary in nature, and having more deliverables. The final hardware deliverable will be fully-functional, high quality, and have passed rigorous testing. The project teams would be smaller and interdisciplinary and make greater use of analysis tools. The faculty advisors will come from different departments. A means will be developed for determining the difficulty of future projects. This two course sequence will be offered starting in the Fall of 2010, with Graduate Design Projects 2 in the Spring of 2011. It is expected that there will be approximately 20 students in this course sequence, based on current interest, enrollment in the Design Track, and Advanced Product Design enrollment.

The subject matter covered in these two project courses will include advanced project management, project scoping, negotiating constraints, team dynamics/conflict resolution, sketching, test methodologies, accelerated testing, designing for test, FMEA (failure analysis), special seminars on analysis tools, ethics/health/environmental issues, intellectual property and prior-art searching, performing competitive analyses, and the carry over subjects expected from the Advanced Product Design class. Some of the expected deliverables from the graduate design project courses include satisfying the sponsor or customer beyond their expectations, producing papers for presentation at industry conferences, developing products that produce a step increase in the sponsor's capability and/or product line, and the creation of new entrepreneurial businesses. It is also expected that the students completing the Design Track will have many employment opportunities.

Additional Track Curriculum

The Advanced Product Design and Graduate Design Projects sequence comprise three of the required core courses in the Design Track. This allows Master's degree students the opportunity to graduate in three semesters if they start in the Spring semester. The mechanical engineering department at CU has a BS/MS program. This program allows students to complete their Bachelor's and Master's degrees in just five years. This is accomplished via the overlap of two graduate

courses for both degrees. A GPA of 3.25 is required of junior and senior undergraduate students to enter this program. Presently, about 10% of the undergraduate students are in this BS/MS program. The graduate design track organization also allows BS/MS students the opportunity to graduate in five years if they start the Design Track sequence in the Spring semester of their fourth year.

The remainder of the Design Track will be comprised of courses that have already been established. The remaining core course will be an applied math course. The optional core courses, of which two must be taken, are graduate classes in; solid mechanics, materials, design optimization, finite element, design for manufacturability, and robotics and mechatronics. The optional or enrichment courses make up the rest of the Design Track. A partial list of these graduate courses include; fluid mechanics, heat transfer, mechanics of composites, vibration, embedded systems, control system analysis, biomedical device design, MEMS, and structure and properties of polymers. It is felt that a student completing this track will be well versed in design and product development, and will have had opportunities to have many practical experiences.

Master's Thesis Option

A thesis option is also available instead of the Graduate Design Projects course sequence. If a student chooses this Research Thesis option, they can substitute the 6 Thesis credit hours for the Graduate Design Projects sequence. Students are encouraged to either complete the Graduate Design Projects sequence or Thesis Research, but not both. Students do not need to make this determination until after the first spring semester when they've completed Advanced Product Design.

Early Initial Results

This first class for this new graduate Design Track, Advanced Product Design, was offered in the Spring of 2010, with an enrollment of 40 students. There are already 18 students presently enrolled in this Design Track. This represents about 15% of the Master's degree students within the mechanical engineering department. These students were already enrolled in the department at the creation of the Design Track, thus demonstrating strong student interest in the Track. The advertising for this new track was limited to new information on the department's web site and putting up a few posters around the department. Based upon information obtained from applications to our department's graduate program for the Fall of 2010, it appears that this number of students in the Design Track will double by the Fall of 2010. Basically, this shows the desire for graduate mechanical engineering students to take design related classes and 'to make stuff work'. The Advanced Product Design class was somewhat arbitrarily limited to 40 students. It was felt that this was a reasonably large number of students for the type of course expected to be offered. It was quite a surprise to see that this course was a bit oversubscribed and indeed, had a small waiting list.

Preliminary feedback obtained from students taking The Advanced Product Design course has been primarily positive. In a rating scheme going from 0 to 5 (5 being the best), the ratings of the course materials and instructors received a rating of approximately 4.5. Since the breadth of topics presented was quite large, many students had a deep interest in only some of the materials. They thus expressed an interest in having these specific topics covered in more depth. However, there was no unanimity relative to these topics of interest. There were also some complaints by the students in the flow of the course, in that the topics did not flow in the same manner as the path associated with a product design. Although it was desired to have such a sequence of instruction, the presentation of materials was constrained by instructor expertise and availability. Finally, the students did not fully appreciate the effect that their choice of project selection would have upon their future assignments in the class.

Subsequent feedback that we have very recently received from the department's industry advisory council suggested that the broad approach was appropriate and that the topics selected were quite reasonable. In fact, they recommended additional topics be taught such as global manufacturing outsourcing, compliance issues, and customer interaction.

As a result of the feedback received this course will be redesigned to some extent. There will be a reduction in the number of faculty teaching the course, one of various textbook recommendations will be used for the course, and approximately 20% of the materials presented will be changed. Additionally, the guidelines for project selection will be more specific.

There also seemed to be a great deal of interest from our department's industry affiliates relative to this design program. This was evidenced by industry's participation in the development of the program, and by their positive response to the program description presentations given to our department's Industry Advisory Council. It is not known if this positive response will correlate to better employment opportunities for students completing the Design Track program. This will be one measure of the success of this new Design Track.

References

[1] http://design.stanford.edu/PD/bigpicture.html.

[2] http://www.segal.northwestern.edu.