The Value of Teaching the Design Process During the Junior Year

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The goal of this paper is relate how focusing on the design process as pedagogy in the junior year enhances the success of the capstone and internship programs. In the School of Mechanical, Industrial, and Manufacturing Engineering (MIME) at Oregon State University (OSU), a junior year course devoted solely to teaching the process of product design is required of all students. This focused offering has led to an improved capstone and internship experiences for the students, increased quality of capstone projects, and a demand from our industry internship partners and recruiters for design process knowledge.

Some History

In 1984 David Ullman left industry and joined the Mechanical Engineering Department. He was hired to teach design in a predominately thermo-fluid faculty. At the time, the design offering consisted of a traditional senior level course in the design of machine elements (i.e. how to design nuts, bolts gears and bearings).

In 1986 he was joined at OSU by Bob Paasch, also a practicing design engineer, to further refine the design offering. Together they developed ME 382, “Introduction to Design” that is required in the junior year. In 1992 the material for this course was refined into a text by Ullman[i] -*The Mechanical Design Process*- which is now in its 6th edition.

During the first years, this course was taught by Ullman and Paasch to about 75 ME majors. With program growth and fusion with the Industrial and Manufacturing Engineering Department to form the School of Mechanical Industrial and Manufacturing Engineering (MIME), the course is now taught by a variety of faculty to about 400 students annually. The structure of the course is described in a subsequent section.

Prior to 2000, capstone projects were managed across all the faculty in the Department. In 2004 they were consolidated under John Parmigiani and later, as the School grew, their management was distributed among three other colleagues including Sharon LeRoux.

Before detailing the course and the resultant benefits, it is important to examine ABET’s current requirements for design and capstone experiences.

ABET on Design

In Criteria for Accrediting Engineering Programs[ii], ABET defines engineering design as (emphasis the authors’):

> “*Engineering design is the* ***process of devising a system, component, or process*** *to meet desired needs and specifications within constraints. It is* ***an iterative, creative, decision-making process*** *in which the basic sciences, mathematics, and engineering sciences are applied to convert resources into solutions. …”*

What is important here is that design is a process that is iterative, creative and is characterized by decision-making. These are topics that can and should be taught much like statics and thermodynamic. This is especially true in light of the description of the capstone experience.

> "*Students must be prepared for engineering practice through a curriculum* ***culminating in a major design experience based on the knowledge and skills acquired in earlier course work*** *and incorporating appropriate engineering standards and multiple realistic constraints*."

These quotes imply that the capstone experience should be based on what was learned in earlier course work. It does not say that the capstone is a place to teach the design process: system thinking, iteration, creativity and decision-making. In other words, according to ABET, design process education, and all that it entails, should proceed the capstone experience.

ME382, Introduction to Design

At Oregon State University we have been meeting this intent for over thirty years with our four-credit hour junior course, *Introduction to Design* (ME 382). This is an experiential design course built around the team solution of an open-ended, ill-defined design problem. It begins by telling the students, who have only taken courses focused on problems with one correct answer, that in 382 there are no right answers and, in fact the problem isn't even fully defined. It ends with a design contest where the teams pit products they designed and built against each other for grade points.

Lectures are given by experienced design professors and meet three times a week for an hour. Labs of twenty-four or fewer students meet for two hours once a week. Where the lectures cover important design process concepts, the labs are managed workshops herding the 3-4 person teams from need to final product, week-by-week. The labs are managed by design graduate students supervised by the lecturer.

During the ten-week design-build-test course, lectures cover topics such as:

- Corporate organization for design
- Design economics
- Creativity
- Capturing the voice of the customer
- Open-ended problem solving
- Team structure and health
- Design project planning
- Concept generation/ evaluation
- Product Generation/ evaluation
- Design for manufacture and assembly
- Sustainable product design
- Real world product development

Measures of Course Success

Offering this course during the junior year has multiple positive effects. First, it off-loads the capstone so it can allow the students to concentrate on applying their education to a true capstone experience.

Second, about 35% of the 400 students who take ME 382 participate in OSU MECOP, a co-op program for industry internships. Students are selected into the program after their sophomore year then they interview with MECOP company representatives. While there are many academic requirements to be in MECOP, companies do not take students who have not taken ME 382. In a recent survey, twenty-nine MECOP employers were asked: "How important is it that students have some knowledge of the design process prior to their MECOP internship?" and given options: "No importance at all", "A little important", "It is nice to have", "Very important", or "I won't take an intern with no design process knowledge". Results showed that 96% thought design process knowledge was either nice to have (48%) or very important (48%).

With a second question, they were given the option between “Student A who had a 4.0 grade point average but no design experience”; or “Student B who had a 3.0 grade point average but had built and tested a device they had designed”, 83% chose the design experienced student, 14% said either would do and 3% chose the student with the high GPA. Some thoughts by the MECOP managers are:

> *“In general, getting interns who have a knowledge of the design process allows us to almost immediately put them in positions where they can add value to the company and gain real experience.”*
>
> *“Interns who have actually applied the design process in any magnitude of project, are much more confident in their ability to come to a professional engineering environment for the first time and begin adding value. While we can teach them a process, we can’t teach them confidence.”*
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> *“I took ME 382 back in 1999-2000. I really enjoyed the class. I am now a manager at XXX and employ MECOP students. The concepts we learned around the design process/requirements/verification testing provided a firm foundation for the work I do daily. Thanks!”*

Third, by separating knowledge about the design process from the capstone experience, the capstone experience can be more successful. In MIME there are four groups of capstone projects: those focused on the SAE Baja and Formula race cars (25%), those focused on aviation and astronautics (20%), those sponsored by industry (15%) and those sponsored internally by faculty (40%). External sponsors contribute $5000 USD plus materials and supplies. Internal projects are managed by Prof Parmigiani, Mrs. LeRoux and others, and must contribute sufficient funds for materials and supplies.

The SAE capstone projects are focused on the Baja and Formula Racing competitions. Since 2005, the OSU Baja team[iii] has entered twenty-two competitions, placing 1st seven times and 2nd eight times. Teams have entered the design competition fifteen times, resulting in six 1st place and three 2nd place finishes. The Formula Racing teams[iv] interact with colleague students at Duale Hochschule Baden-Württemberg-Ravensburg (DHBW), Germany. Together, they compete in the US and internationally. Since 2010 they have won fully one half the ten events they have entered in the US and 35% of those they have entered internationally.

Every year the Baja and Formula Teams team raise their own sponsorship money. In the words of Professor Bob Paasch, the MIME faculty member responsible for the SAE projects:

> *“Every student comes to the Baja or Formula Racing projects with a knowledge about how to solve design problems professionally.   Without the prior schooling in the design process, we would not have been anywhere near as successful as we have been. Raising the money to support this international program has gotten easier with success and success has been built on the knowledge gained in ME 382.”*

Students with a strong interest in aviation and astronautics have been successfully competing in national and international AIAA Design-Build-Fly (DBF) and the Experimental Sounding Rocket Association rocketry competitions. The DBF teams have consistently placed at the top of the universities that do not have aerospace engineering programs. OSU is ranked #2 in the country for success in high altitude competition rockets. This success is due, in large part, to the emphasis in design, manufacture and testing in the mechanical engineering curriculum.

According to Nancy Squires, who manages the AIAA capstone projects:

> "*Our Aero capstone students are being hired by top technology companies in the aerospace sector, with some recruited directly from the competition venue. Engineering employers seek students who engage in technically challenging projects, work collaboratively as a team, and demonstrate impact and commitment to mission success, all traits learned in ME 382. With their success in intercollegiate competitions have landed students positions with companies such as Boeing, SpaceX, United Launch Alliance, Northrup-Grumman, Raytheon, Lockheed-Martin, Blue Origin, Aerospace Corporation, Virgin Galactic, Orbital ATK, Space Dynamics Laboratory and NASA*."

An informal survey of industries who sponsor non-SAE, non-AIAA capstone projects resulted in the following quotes:

> *"We had a cracker-jack team back who built a proto-type shoe press for us – not only was it an excellent proof of concept, it was highly functional and ended up being a production-worthy piece of equipment."*

> *"Not only do many of the students I have had the pleasure to work with on design projects have the ability to do the work, they also have the ability to organize to do the work effectively – beginning with customer requirements through managing the work flow and work assignments to ensure success."*

> *"The students I have worked with have taken ownership of their projects, independently problem solving and proposing their own solutions to design challenges. They required little input to achieve solid results".*

> *"Our project was not terribly complicated, but it had some challenging engineering problems that took analysis and skill to work out solutions. The students on the project did a good job listening to us and working to understand our needs. While we made multiple suggestions and adjustments to the tool, it was a good experience and our company came out with a workable product "*

Summary

The School of Mechanical, Industrial and Manufacturing Engineering (MIME) at Oregon State University offers a very vibrant and healthy capstone experience to its four hundred students each year. It fully meets the intent of the ABET requirements and is, for the most part, self-sustaining. The success of this program is directly dependent on teaching the design process prior to the capstone course, not as a part of it. It gives the students greater opportunities for success during internships, co-op experiences and the ability to begin their engineering careers with real-world experience.

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[i] David G. Ullman, The Mechanical Design Process 6th edition, 2017, www.mechdesignprocess.com

[ii] CRITERIA FOR ACCREDITING ENGINEERING PROGRAMS, Effective for Reviews During the 2017-2018 Accreditation Cycle, ABET, Oct 2016. http://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2017-2018/

[iii] Beaver Racing http://beaverracing.org/

[iv] Global Formula Racing http://www.global-formula-racing.com/