

A Multi-faceted Design Process for Multi-disciplinary Capstone Design Projects

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Engineers are called upon to design a wide variety of devices and systems, typically in a multi-disciplinary team environment. We try to incorporate this design environment into the senior capstone design experience in mechanical engineering at NMSU. In this two-semester sequence, each design team is led by a student manager, often a graduate student from another engineering department. Since these student managers often have little more design experience than the undergraduate students, it is useful to present a fairly structured framework for the design teams to operate within. This multi-faceted design procedure helps walk the students through the maze of issues that must be considered in engineering design. This design process is modeled after the methods that we have used in delivering customer design and development projects under contract for actual engineering applications. The approach fosters a stronger team-oriented working relationship with the client or company sponsoring the project, enables us to train our students in one product development process, and helps the team members learn what to expect in working together.

During the first semester of the senior experience, the multi-faceted approach to product design and development is presented to the students as a sequential process, with each step following week by week through the semester. When the students enter their second semester, they have some basis for seeing the “big picture”, and the multi-faceted process is then presented as a concurrent engineering environment, to help the team members stay on track with multiple design issues.

This design process was originally adapted from personal experience for use with the senior mechanical engineering capstone course. During the Spring semester of 2000, the method was applied on a pilot-basis to a team-taught projects class involving approximately 70 mechanical engineering and 15 industrial engineering students, with 8 technical writing students serving as consultants to each team.

During the Spring 2001 semester, the capstone course will include full participation from mechanical engineering (two faculty members), industrial engineering (one faculty member), and technical communications (one faculty member). Typical semesters include fifteen to eighteen distinct project teams, with upwards of 90 undergraduate students enrolled in the capstone projects

class. Each faculty mentor is responsible for five to six project teams.

This paper will present an overview of the design process originally developed for use within the mechanical engineering senior capstone design course, and how the process is being adapted for use in multi-disciplinary team projects.

The twelve-faceted design process used in the senior capstone design class in engineering at New Mexico State University is outlined here. During each facet, students follow a Plan-Do-Check-Act (PDCA) cycle. During the “Plan” stage for the facet, the student teams, working with their graduate student manager, who is in turn being guided by the faculty mentor, develop a work breakdown structure for the tasks that need to be accomplished during the coming week. Each team member is given an individual assignment. The students then work on their individual tasks alone, or in small groups of two people, to “Do” their assigned task. At the end of the week, the students turn in their assignments to the team manager, who compiles all of the information into the DesignPlanner™ for the team. Quite often, the students choose to schedule working sessions during the intervening week to collaborate on their individual tasks. This is particularly true when the team is developing their preliminary drawing package mid-way through the semester. At the end of each work-week, the team meets to “Check” the submissions and determine if all needed information was obtained and is sufficient. The team has a weekly meeting with their faculty mentor, during which they review the results of the previous week, and develop an action plan for the coming week. This step concludes the PDCA cycle, with the students seeing that their next step results from “Acting” on their previous results in the context of the overall design process.

Facet 1. Recognize and Quantify the Need

- Market Demand
- Assess competing solutions for the need
- Budgetary Parameters
- Develop formal Needs Statement and Statement of Work for Customer Approval

Facet 2. Concept Development

- Brainstorming Techniques
- Literature Review of alternatives
- Consensus Building

Facet 3. Feasibility Assessment

- Technical Feasibility
- Economic Feasibility
- Schedule Feasibility
- Performance Feasibility

Facet 4. Preliminary Design

- Preliminary Drawing Packages
- Assembly and Component Drawings
- Bill of Materials and Supplier Identification

Facet 5. Establishing Design Objectives and Criteria

- Performance Specifications
- Design and Implementation Specifications
- Evaluation criteria

Facet 56 Analysis of Problems & Synthesis into the Design

- Formal Problem Solving Method
- Assembly Drawing "Big Picture" integration
- Systems integration

Facet 7. Engineering Models - Simulation and/or Hardware

- Software simulations and CAD models
- Rapid Prototype and physical representations
- Proof of Concept Prototype

Facet 8. Detailed Design (DFx)

- Comprehensive Drawing Packages
- Line by Line review of codes and standards
- Design factors include: Safety, Manufacturability, Maintenance, Assembly, Manufacturing, Disassembly, Recycling, Quality

Facet 9. Production Planning and Tooling Design

- Pre-Production Prototype
- Flexible work cell design, die design, fixtures, tooling, automation
- Process diagrams and process flow sheets

Facet 10. Pilot Production

- Cell acquisition
- Operator training
- System commissioning

Facet 11. Transition to Commercial Production

- Capitalization
- Standardization and interchangeability
- Mass Customization

Facet 12. Product Stewardship

- Sales, Service, and Support
- Consumer feedback for continuous product improvement
- Product Line Migration
- Product Maintenance and Recall Procedures
- End of Life considerations

During our two semester sequence, students in the first course, ME427, are introduced to this process as a sequential process. One facet is introduced each Monday of the semester, in a short 30 minute lecture, followed by a 30 minute exercise. The students then break up into their project teams, and apply the material from the lecture to their team project. Faculty mentors and graduate student managers act as facilitators to smaller project teams consisting of five to seven undergraduates. The project teams are structured such that each team has approximately 50%

ME426 (first semester) and 50% ME427 (second semester) students. Each team is assigned a graduate assistant as the team manager. Often, the graduate students are either enrolled in an engineering project management course, or are involved with a related project for their MS degree.

Concurrently, the ME427 students, who have already been through the sequential process in a prior semester, are encouraged to employ concepts of concurrent engineering, and apply the facets in parallel, during 30 minute lectures on Wednesday of each week. In the Wednesday sections, the ME427 student learn about a detailed design topic (DFx), such as Design for Safety, Assembly, Recycling, Migration, etc. In this way, the ME427 students mentor the ME426 students, and bring advanced knowledge about design requirements into the design process very early in the semester.

The English 490 students from technical writing and the IE480 students from industrial engineering all participate in the common Monday sessions, to get a broad perspective of the design process and the steps that are being used in completing each of the team projects. On Wednesday of each week, the technical writing students work within their discipline, and achieve cross-learning by comparing experiences and techniques that the individual students are applying in their projects.

The IE480 students likewise will receive discipline specific training in their Wednesday sections about topics such as engineering project management, economic analysis, OSHA compliance, and work breakdown structures for production planning of their design.

On Friday of each week, the team should complete a first draft of one more section in their final report, the Technical Data Package (TDP), that is in direct support of the design drawing documents. Each of these drafts should be retained by the team manager in the project DesignPlanner™. All raw materials prepared by the student team members are collected by the team manager in the DesignPlanner™ as well. Students are provided with contact logs, forms for quote requests from vendors, trip reports, sample meeting agendas, minutes, and analysis examples. As the students are assigned tasks during each week, they see immediately that each of their individual contributions become part of the final report, and the DesignPlanner™ becomes a repository for all project archival information that the students can subsequently refer to. Each project team is provided with a FTP site on a web server for the class, so that they can readily exchange electronic data files (such as CAD drawings, photographs, and draft documents). Each team is also provided with a link to a web site, wherein they can exchange progress reports and information not only with other team members, but also with their project client, who is often located off-campus.

Mid-way through the semester, each team will undergoes preliminary design review with the faculty mentor team. The project team should have the draft versions of their design drawing package and the first several sections of their technical data package ready for review at this session. The mentor team red-lines the drawings and TDP for revision by the student project team. The student team should be prepared to support and discuss all calculations, analyses, reports, and

related information at the PDR. The PDR consists of drawing reviews, mechanical design analysis review, systems overview review, and TDP/draft final report review. The students all know that the PDR is a review of work in progress, and the drawing package and report are expected to be well outlined, but incomplete. Essentially, the PDR has evolved over time into an interactive grading session, where the faculty members review the student document, makes recommendations, queries the students on the team about their thought process for making a particular design decision, and then makes suggestions for ways to improve either the design itself, or the presentation of the material discussing the design. The faculty mentors truly act as a “guide on the side” during this process, pointing out areas of improvement, and examples of items to be corrected. In this way, the students not only get a “graded report” returned to them, but they also gain insight into the faculty members’ thought process behind making a particular correction. One student, for example, during the Fall 2000 semester PDR, offered that he felt like he had “learned more engineering in the past two hours than in the four years I have been in school.” Of course, the student appreciated that his four years of preparation allowed him to get to this point. For many students, this is the first time they have actively seen anyone evaluate their papers and analyses.

Prior to the end of the semester, each team undergoes a critical design review with the mentor team. This will be a second review to assess progress, and determine if the design drawings and TDP have been corrected following the PDR. Normally, in a commercial environment, the CDR represents a major commitment of corporate resources, and may last one or more weeks. In addition to the design drawings and TDP, the team should also have an outline of their presentation ready for review. During finals week, each team makes a 30 minute presentation to the rest of the teams, faculty, and project clients.

The logistical hurdles of working across departmental and college boundaries are significant. A key element to success is the concurrent scheduling of the various departmental courses at a common time, in a laboratory scheduling format. In this manner, most students are available for project team meetings and faculty mentor meetings during a pre-determined set of time-slots. They are then free to work on their individual assignments in accordance with their personal schedules.

A suggested outline for the weekly tasks and topical coverage is presented in Table 1. This schedule may be adapted to account for scheduled breaks and holidays, or to allow increased or decreased coverage of certain topics. For example, while we discuss many items related to commercial production and product stewardship in the classroom sessions, the students typically do not provide an in-depth discussion of those later topics in their final design reports.

Table 1. Typical Semester Schedule

Wk	Monday	Wednesday	Friday
1	Introduction to the Semester Projects	ME427: Getting Down to Business	All Read: On-Line learning materials
2	ME426: Introduction to the Design Process and Recognize & Quantify Need	ME427: Preparing a Statement of Work	Customer Visits Due
3	ME426: Concept Development	ME427: Engineering Design Communications	Needs Statement Due
4	ME426: Feasibility Assessment	ME427: Technical Data Package	Design Concepts Due
5	ME426: Preliminary Design	ME427: Management & Document Control	Feasibility Assessment Due
6	ME426: Design Specifications	ME427: Bill of Materials, quotes, and purchasing.	Objs & Specs Due
7	ME426: Analysis & Synthesis	ME427: Design for Safety and Compliance	Prepare DWGs and TDP
8	Preliminary Design Review Sessions	Preliminary Design Review Sessions	Technical Data Package Due at PDR
9	ME426: Engineering Models & Detailed Design	ME427: Design for Manufacture & Assembly	Revise DWGs and TDP
10	ME426: Production Planning and Tooling	ME427: Design for Quality, Reliability, and Maint.	Revise DWGs and TDP
11	ME426: Pilot Production Commercial Production	ME427: Design for Performance – Optimization	
12	ME426: Product Stewardship	ME427: Design Report, TDP, and presentation	Analysis & Synthesis Due Detailed Design Due
13	Critical Design Review Sessions	Critical Design Review Sessions	Production Topics and Stewardship Due
14	Final Formal Presentations	Final Formal Presentations	

A wide variety of product design and development processes are used by industry today. The process summarized here is not intended to be all-inclusive, but rather is meant to provide a relatively simplistic, yet reasonable thorough, process that students can use in completing relatively complex design projects. With this structure, student teams are able to see commonality between their projects, and can produce a meaningful design result in a short period of time. At the conclusion of the project, the students begin to appreciate the value that a formalized concurrent engineering method can bring to a design.

In addition to understanding the role that various disciplines play within the context of product design and development, the students also gain confidence in being able to tackle complex and poorly-defined problems that would have been overwhelming to them just a few months earlier. The two-semester nature of the capstone design project fosters cross-learning between the students, and helps them make the transition from “student” to “engineer.”

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