INSTRUCTOR'S MANUAL
FOR
THE MECHANICAL DESIGN PROCESS

BY

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CONTENTS

I. INTRODUCTION

I.1 Course philosophy

The *Mechanical Design Process* is a compendium of design best practices woven together and resulting in a process to get from need to a quality, cost effective product.

In the preface to the text the following four tenants are stated as basic beliefs about teaching the mechanical design process:

1. The only way to learn about design is to do design.
2. In engineering design there are three types of knowledge a designer uses: knowledge to generate ideas, knowledge to evaluate ideas and knowledge of how to structure the design process. Idea generation comes from experience and natural ability. Idea evaluation comes partially from experience and partially from formal training. Most engineering courses are aimed at developing analytic evaluation skills. Generative and evaluative knowledge are forms of domain specific knowledge. Knowledge about the design process is largely independent of domain knowledge.
3. A design process can be learned that will help result in quality products provided there is sufficient ability and experience to generate ideas and enough experience and training to evaluate them.
4. A design process should be learned in an academic setting and, at the same time, in an environment that simulates industrial realities.

The information given in this instructor's manual to support these four tenants is based on thirty five years of personal experience and extensive communication with other educators. Before presenting material to help in organizing the course, grading design projects and developing good design problems, some general comments about the text are necessary.

The techniques given in the text are presented in a serial manner: understanding the problem, concept generation, concept evaluation, product generation and product evaluation. Actual design problems are never serial but are always a mix of the above five topics. However, writing is a serial form of communication. Thus it is impossible to write a book about the parallel, recursive, iterative nature of design without giving the impression that it too is serial. It is important to emphasize that the techniques can be used in the order in which they are presented, and, more importantly, can be used whenever they are needed. I have tried to emphasize this in the text.

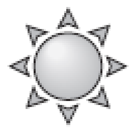
The fifth edition has exercises at the end of each chapter. These are all design problems with no correct answers and thus no solutions are given. Design is best learned by doing, then reviewing with others.

Lastly, this text is still in middle of its own design process. The field of design methodology is still young and fairly naive. A book on the design process written five years from this writing will be much different as understanding of the design process is increasing at a rapid rate. Thus, I encourage you to find fault with the information presented here, to try to develop improved techniques and communicate them to me as I am still learning.

I.2 Best Practices in the 5th edition

For years people have looked at *The Mechanical Design Process* as a compendium of best practices. However, it was never made obvious what those practices exactly were. The fifth edition ties these into the chapters and case studies. The 50 best practices are itemized in Table 1.1 (page 7). They are a flag in the text to something important.

Best practices are noted with icons like:



Best Practice:
Identify product
customers.

I.3 Case Studies in the 6th edition

13 case studies support the material in the book. They are all written with industrial partners and all exemplify how the best practices in the book are used in industry. These have been published as a separate book, *The Mechanical Design Process Case Studies*, and individually in PDF format. See the book's website www.mechdesignprocess.com for details on how to obtain these. Where material in the text supports a case study there is an icon such as:

Reinventing the
See-Saw at Big Toys

Case studies available are:

- Idea to Product in One Day
- A Soft Ride at BikeE
- Multi-duty PC Boards at Sound Devices
- Spiral Product Development at Syncromatics
- From Constraints to Components at Marin Bicycles

- Reinventing the See-Saw at BigToys
- Unsticking a concept at MAGICWheels
- Achieving a single truth at Eclipse
- Designing a Hybrid Car at BMW
- Designing with Mushrooms at Ecovative
- Supporting Life in Space at NASA
- All Hot And Nowhere To Go at Chart Industries
- Redesigning the Ceiling Fan at the Florida Solar Energy Center
- Supporting Life in Space at NASA

I.4 Templates supporting the 6th edition

25 templates are available for download and student use available on www.mechdesignprocess.com. Most of these templates have Microsoft Word© form fields in them to make "filling in the blanks" easy. This includes Text Form Fields and Dropdown Form Fields. You can use the templates as provided or edit them to suit your needs. To edit the fields in Word, display the Forms Toolbar (View, Toolbars, Forms). Unlock the form to edit (right icon that looks like a lock). Be sure to relock it or the drop downs won't work.

Those template marked with an "*" are Excel worksheets (5, 6, 13, 14, 18). They automatically calculate important design information. Templates are noted in the text with the following icon:

T

Templates available are:

1. Product Decomposition
2. Team contract
3. Meeting minutes
4. Team health inventory
5. Design for Sustainability *
6. Plastics ID *
7. Design Report
8. Product Proposal
9. Pro-Con Analysis
10. Project Plan
11. SWOT Analysis
12. Technology Readiness
13. Plastics Part Cost Calculator *
14. Machined Part Cost Calculator *
15. Morphology
16. Voice of the Customer
17. Reverse Engineering for Function Understanding

18. Personal Problem Solving Dimensions *
19. Test Report
20. Vendor Selection or Make/Buy Decision
21. DFAssy
22. FMEA
23. Bill of Materials (BOM)
24. Engineering Change Notice
25. Patent Prospectus

Please send any corrections or suggestions for other templates to: Professor David Ullman, ullman@engr.orst.edu.

I.5 Meeting ABET Requirements

The ABET definition of design is (underlining added to emphasize the material covered in this book):

> "Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet a stated objective."

In the past, this definition included more details, specifically:

> "… Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing and evaluation. The engineering design component of a curriculum must include most of the following features: development of student creativity, use of open-ended problems, development and use of modern design theory and methodology, formulation of design problem statements and specification, consideration of alternative solutions, feasibility considerations, production processes, concurrent engineering design, and detailed system description. Further it is essential to include a variety of realistic constraints, such as economic factors, safety, reliability, aesthetics, ethics and social impact."

As can be seen, the material in this book directly supports these ideals. Further, this book emphasizes communication, teamwork and other non-engineering capabilities emphasized by ABET.

II. ORGANIZATION OF A TYPICAL COURSE

I have taught the material in this text to junior mechanical engineering students, mechanical engineering graduate students and to professional engineers. A course based on this text can be taught in ten weeks to junior level students. This course is built around a design project resulting in hardware. A syllabus for this course is presented Appendix A. The highlights of this syllabus are covered here.

This course has four interwoven objectives:

* To learn about the process of design in order to generate better quality designs in less time.
* To learn about the organization of design within a company.
* To learn how to be more creative in solving design problems.
* To learn how to design as part of a group activity.

Additionally, since the students at most Universities have virtually no opportunity to see any of their ideas refined to hardware, a fifth goal is:

* To refine an idea to hardware and test the hardware against the initial requirements.

To accomplish all of these goals the course is focused around a design project. There are many different types of design projects or problems that can be used in this course; they are listed and discussed in Section IV of this Manual and many more can be found on the web. In the course the design problems are solved by teams of students. The organization and grading of the teams is discussed in Section III of this manual. Other details about the course are discussed in the remainder of this section.

II.1 Scheduling

As shown in the syllabus, a course based on this text is taught in ten weeks. This is far too short a period to get all the information across to the students and have them complete a design project. Thus, I concentrate on problem understanding and conceptual design, and skim over some of the introductory and product design information. We then reinforce the information by requiring use of the methods in the senior projects.

Other professors have covered this material in two quarters using the first quarter to study the text and the second to execute a design project.

Another feature of the schedule shown in the syllabus is that I only allow the students to spend the last three weeks of the term to build and test hardware. In other words, I force them to have all the details worked out on paper and with prototypes before they begin building the final product. I try to encourage as many changes on paper as possible because they are less expensive than changes in hardware.

II.2 The Use of Design Notebooks

In order to monitor progress and to foster good work habits, all work concerning the design project is done in a design notebook. This includes all sketches, notes, design ideas and homework. Every page in the notebook must be numbered at the beginning of the term. No pages can be removed and each page must be dated and initialed when used. In other words, everything done on the project is included in the notebook. Each notebook is collected at the end of the term and graded on the number of "quality entries" it contains. A quality entry is a significant sketch or drawing of some aspect of the design; a listing of functions, ideas, or other features; a table such as morphology or decision matrix; or a page of text. Entries that are unintelligible are not "quality entries." The grading scheme I use is:

Grade of 100% for 50 or more quality entries
Grade of 90% for 40-49
Grade of 80% for 30-39
Grade of 70% for 20-29
Grade of 60% for <20

Students have a lot of trouble getting used to a design notebook; it is foreign to anything they have done before. They need continuous reinforcing with statements like, "It is just like a diary of all your efforts on the project," "Put every thought about the project in the notebook", “Neatness does not count, put down all your ideas” and "Take the notebook to bed and in the shower with you." I have not been firm about writing only in ink as are many employers, but I have been rigorous about their dating and signing numbered pages.

Since all the work on the project is in the design notebook, copies of pages of the notebook suffice for home work, forcing the students to keep the project on schedule. Additionally, since each page is signed and dated, plagiarism has not proved to be a problem. To date, no student has complained that making copies is an inconvenience.

The design notebook also monitors how each student is progressing in the course. I inspect each notebook every couple of weeks during the course, to encourage its use and to learn who is contributing to the team effort. Further discussion on the use of the notebook in determining team problems is found in Section III.

One disconnect is the use of template and other material from the web. This problem is not unique to this course. I have the students print out the web material and staple it into the notebook.

II.3 The Company Procedure Bulletin

Although not used in the syllabus in the Appendix A example, I sometimes use a company procedure bulletin (Appendix B) to control the flow of the design project. This bulletin is based on one I developed for a small company that had trouble developing new products because the management altered the course of the project every few weeks. The bulletin forces the design team to act like a mini-company. Each member of the design team is given a role in the company and each phase of the design process must be signed off by the CEO (me) before progressing to the next phase.

The use of this bulletin adds another level of reality to the solution of the design problem. Following it, along with keeping a design notebook, makes the students aware that there is more to design than bending metal.

III. STUDENT DESIGN TEAMS

I use student teams in all my design oriented courses, for many reasons. First, in industry very few products are designed by a single individual. Generally, a team of individuals is necessary for even the simplest product. Thus, using teams is realistic. Second, students need experience in working together. Third, project evaluation and grading are easier as there are fewer projects to deal with.

III.1 How to Organize Student Teams

I assign students to teams rather than let them choose their teammates. I do this primarily for balance. In my classes the students range from certified welders who are working on a mid-life degree to twenty year old students who have never held a hammer. They also range from experienced drafters or CAD professionals to students who have avoided a mechanical drawing course. Thus, on the first day of class I pass out a questionnaire that asks for brief statements about their mechanical and drafting or CAD experiences. I then build balanced teams with one "old hand" and one person with at least some professional drafting or CAD experience.

I use three person teams almost exclusively. Two person teams are unrealistically small and do not force dealing with group dynamics. Teams with four or more members usually result in some members doing little to contribute to the team. However, due to the number of students in a given section I usually end up with some four person teams and, due to attrition (dropping the course or illness), some two person teams.

An additional benefit of assigning the teams is that students have noted that they enjoyed meeting and working with some of their classmates whom they didn't previously know.

III.2 Team Forming, Team Contracts and Team Health

The last half of Chapter 3 focuses on design teams. In this section three documents are introduced and are all templates on the web site: Team Contract, Team Meeting Minutes and Team Health Assessment. The Team Contract is used during the first meeting of the team. It forces them to itemize their team goals, performance expectations and strategies for conflict resolution. The Team Meeting Minutes are intended to be used to record the agenda, discussion and action items for each meeting. Finally, the Team Health Assessment lists 17 measures that can be indicators of team problems. These can either be done independently, by each team member and handed in for review by the faculty, or can be used within the team for introspection. Problems revealed during the assessment can be addressed using the techniques in the next section.

III.3 How to Resolve Team Problems

Some of the teams experience problems during their time working together. Most resolve these problems themselves. However they are encouraged to come to me if they are having trouble. Some suggestions are:

* **One team member is not contributing.** This is the most typical problem encountered. It can be caused by disinterest, language or cultural difficulties, dominance by another group member (see next item), living situation differences, or fear of making decisions when there are no "right answers." One way of determining the problem is to look at the teams notebooks which I usually do every couple of weeks. However, if I suspect that someone is not contributing, a more frequent review or the Team Health Assessment can often give clues as to the cause of the problem.

* **One team member is dominating the others.** One pitfall of student teams is that the experienced people sometimes lose patience with the less experienced members of the team and begins to dominate. Usually, these experienced students are mature and try very hard not to dominate, but the other students sometimes defer to them. Again, the note books can give some aid in determining this problem. Often, the experienced person will come to me in frustration alerting me to the problem. There is no good solution other than to encourage patience and to remind the experienced student that he/she may face the same problem after graduation.

* **Team members can't agree on major decisions.** This problem is usually resolved through the use of the decision making methods introduced in the book. Review with the team, how they are making decisions by walking them through Figure 4.5.

* **Team members can not work together.** Usually students can resolve their differences. If not they are encouraged to come to me for resolution. This is not a frequent occurrence. When it does occur, usually I can help find a solution through one of the above suggestions or through my intervention to organize time or work tasks. However, sometimes there are complete communication breakdowns and the group self destructs. This has only happened once. My resolution for this group was to have the students complete the project independently.

III.4 Grading the Teams

Grading each student's contribution to the team is difficult. I have used the following procedure for about ten years with good success. All work done by the team is given a team grade. This generally includes the result of any design contests and reports. This team grade is then weighted for each student in the team based on their own, confidential self analysis. Specifically, at the end of each term, the form below is handed out to be filled in by every student.

PROJECT INVOLVEMENT QUESTIONNAIRE						
NAME	REQU DEV	CONCEPT DEV	ANALYSIS	COMMUNICATION	WORK WITH TEAM	TOTAL

Each member of the team evaluates every member (including him/herself) for the percent contribution to the project in each of the categories. The evaluations are averaged in order to find each student's contribution and the weighting factor is made proportional to the average. If there are, for example, three students on a team and each makes the same (33%) contribution then all will get the same grade. More than fifty percent of the teams will have all members rate everyone's contribution as equal.

However, if one team member of a three person team makes a 40% contribution, one a 25% contribution and the third a 35% contribution then the grades will be corrected by the difference from 33%. Thus, if the group grade on a report was, for example, 85% then the first student would get 92% (85+(40-33)), the second would get 77% (85+(25-33)) and the third 87%.

This scheme has been well received by the students and usually the correlation among the scores of the team members is fairly high. In other words, even the student who makes little contribution will give him/herself a lower score. Seldom is there a team where all the members have a different perception of who contributed to the effort. In cases where there is a difference, the design notebooks give a good indication of who contributed what to the effort.

IV. DESIGN PROBLEM CONSIDERATIONS

As stated in the introduction "the only way to learn about design is to do design." To have students design within the academic environment of time, manpower and budget constraints, is a challenge. A number of considerations are needed when selecting design problems for the students. In this section the issues which should be considered and guidelines for structuring problems are given.

IV.1 Completeness of Problem Definition

When I first started teaching design courses I had the feeling that I needed to know solutions for the problems before the students began solving them. This is only possible with problems that are well defined and that contain a limited number of answers. As these types of problems are not really design problems I came to the realization that I only needed to have some feel for the range of solutions to keep the size of the problem and the need for resources in control. Thus, I often assign problems for which the solutions are as much a surprise to me as to my students.

Assigning ill-defined problems is important for two reasons: First, a major part of the design process is understanding the problem. It is essential that students get experience in working without all the information. Second, that is the way it will be when they graduate from college.

One consequence of assigning ill-defined problems is that, in some student's eyes, I am no longer an "all-knowing" professor. In an analysis class, when a student asks a professor a question the professor is suppose to know the answer. In a design class, with ill-defined problems, I often do not know the answer or, if I do have an idea, I often won't give it. Unfortunately, this implies, to some students, that I am ill-prepared to teach to the course. I have never found a way around this perception.

IV.2 Final Product of Assignment

A second classification of design problems is based on whether a paper solution will be the final product or if hardware will be produced. Many students in my mechanical design classes have never built anything. They have little feel for the manipulation of materials nor any appreciation for the difficulty involved in actually getting a piece of hardware to operate like the image in the designer's head. For these reasons, I require hardware to be built in all my design courses. However, this puts an added burden on the student, me and the facilities in my department. The only way I have found to manage the burden on my department's resources is through the use of kits and design contests as discussed in subsequent sections.

IV.3 Tinkering versus Design Process Structure

A third issue is the rigidity to which the students will be required to design on paper prior to building hardware. One approach to design is to fully design on paper before making hardware. The other extreme is to design by tinkering with hardware. I call this approach the "back yard method." Although I realize that some tinkering is a necessary part of the design process (I am a tinkerer by nature), I do not think that the purely "backyard method" encourages good design practice and thus I discourage it. I require the students to produce drawings and then hardware giving extensive encouragement to build prototypes of subsystems in order to convince themselves that the device will operate as they had planned. I do not, however, allow them to actually begin building their final product until they have a full set of drawings.

IV.4 Many Small Sub-Problems versus a Single Large Problem

There are two different types of problems that can be assigned in this course: small problems to exercise each technique or a single large problem to which all the techniques are applied. I have supplied problems of both types in the text. Personally, I like the one long problem best as they give a total picture instead of a number of disconnected snapshots.

IV.5 The Value of Design Contests

Design contests have proven to be a good method for teaching the design process. All students begin with the same set of design requirements easing the burden on the course instructor. More importantly, the students get to see a range of results that naturally occur in design. Finally, the thought of having to build a device and to test it in a contest against the other students adds an additional incentive to do a good job. I have found that design contests add a great deal of enthusiasm for the course.

Design contests have been used for years in teaching situations have in the recent past been popularized by Woody Flowers of MIT. He has had good television and popular press coverage for his course which is taught at the sophomore level. The contest structure I will discuss here follows that done at MIT with the following exceptions: 1) It follows the structured design process espoused in the text. 2) It forces the design on paper before committing to hardware. 3) It utilizes less department resources. This last item needs more comment.

Most schools do not have the faculty nor the shop space or equipment that MIT has. For example, I have to stage the design course for 80 students by myself or with one co-faculty member and two or three teaching assistants. Thus, I have to be very careful about the amount of preparation time and time for project guidance. Additionally, we have very limited shop space and equipment. In the following sections I will discuss the use of "kits" of materials to control the demands both on my time and the facilities. Beyond the use of kits, having the entire class working on the same design project is necessary for the student-teacher ratio with which I have to deal.

An issue that arises in design contests is whether to make them head-to-head competitions as with a race or to allow the teams to interact both offensively and defensively as in a game. The contests used at all allow both offensive and defensive tactics to be designed into the machines and used in the contest. In an effort to make the experience as realistic as possible I feel that few design situations result in devices directly fighting each other. Additionally, the result of interaction competitions are too dependent on the skill of the operator rather than the quality of the device. Thus, I have moved toward head-to-head competitions with no machine interaction. This does not seem to have dulled the student's enthusiasm for the projects nor the actual competition.

IV.6 The Development of Kits to Support Design Contests

One problem at Oregon State University is the limitation of equipment and space. Additionally, our students have no means for getting training in the use of manufacturing equipment. Many arrive on our campus with extensive experience, however most have little manufacturing skills.

To control these issues, I have used design contests and sometimes supply the students with a "kit" of materials to be used to solve the contest problem. In these kits, materials are limited to those that can be worked with the equipment in our shop. Thus we only supply cardboard, wood, thin plastic sheet, thin steel rod and sheet metal that can be easily worked. Beyond the standard hand tools the students can use:

* A manual shear
* A three foot break
* A horizontal band saw
* A vertical band saw
* A drill press.

Another issue that must be faced in developing kits is the source of power that the students will be able to use. In the past I have supplied DC electric motors, springs and/or rubber bands (surgical tubing). I have thought about allowing the use of flywheels, compressed air and human power, but all of these seemed either dangerous or potentially too large to be of use. The use of DC electric motors has worked out well. The students have little or no experience with motors and the modeling of power flow from source to load. Using these motors makes it easy for the students to learn about torque/rpm relationships (nearly linear for most common DC electric motors) and how to model power transmission system. Additionally, these motors can be purchased very inexpensively ($1-$3) from the sources below.

H&R Company, Inc.
353 Crider Avenue
Moorestown, NJ 08057
http://www.herbach.com/
800-848-8001

C & H Surplus805 Highland Ave
Duarte, California 91010
http://www.candhsurplus.com/
626-256-7907

American Science and Surplus
Various locations in the Chicago area
http://www.sciplus.com/category.cfm/subsection/18/category/174
888-724-7587

IV.8 The Use of Redesign Problems

Another type of problem I have used is what is called a redesign problem. In this type of problem the students are given a working product and told that they have been hired as consultants to redesign the product to meet some new specifications. I have not used this type of problem in support of the course based on this text, but have used them in other courses where the goal was to teach about the design of machine elements. In these courses the students have to dissect and analyze the current design and suggest design modifications to improve the product.

This type of problem can be used to support this course by having the students follow the design process to determine the design specifications, establish a functional model, develop alternative concepts for various components or assemblies, and evaluate the components.

IV.9 The Importance of Industrial Sponsors

Industrially sponsored design problems are used in many design courses. The positive features of this liaison are having the students associate with practicing engineers, having the students work on "real" problems and improving further involvement of academia and industry. Negatively, industrially supported design problems usually require extensive time for both the academics and the industrial sponsors. Additionally, I have found that industrial sponsors often already have specific solutions in mind and primarily want their idea reduced to practice. Finally, at some universities (mine for one) there is little industry near by and no strong connections between the department and industry. Developing sponsored design problems becomes more difficult at these schools than at those with strong industrial ties.

I have never found a way to combine the design contests with industrially sponsored projects. However, since I sometimes have the same students for two design courses I have used contests in one (design methods) and industrially sponsored projects in the other (the design of machine components).

V. STUDENT'S REACTIONS TO THE COURSE

Courses taught from the material in this text are somewhat different than those taught in most other engineering courses, thus the students' reactions to the course tend to be different. In general students either find this course refreshing as it is closer to what they thought engineering would be or they find it bewildering as there are no correct answers and no single, correct procedure.

In the eyes of some students, this course is not well organized. In comparison to the analysis courses that the students have had for most of their academic life, these observations are, to some extent, true.

Another problem with the material is that many students feel that it takes too much time and work to complete a design assignment. However, most students take great pride in their results even if they don't work as planned.

Most of the positive comments about the course come after the students have taken a summer or full time job. I often hear that they have been able to introduce these techniques to their colleagues who have either heard about them but not begun to implement them or are just beginning to make use of the techniques. It is always a pleasure to hear of knowledge flowing from academia to our industrial customers.

VI. SUPPORT FOR COST ANALYSIS

I feel it is important for students to actually calculate a realistic cost for at least one product they design so that they can get some feel for the effect of their design decisions. They especially need to see the effects of tolerance decisions and the relation of cost to volume. There is no need for great accuracy in these estimations, they are used more to see the effect of cost on their design decisions.

In the text there is some information on cost estimation. On the website there are templates (actually Excel code), I have developed to aid students in determining the cost of machined metal components and injection molded plastic components.

VII. OTHER USEFUL SOURCES OF INFORMATION

Although there is no organization in the United States that focuses on generating and collecting material for engineering design education, there is in Great Britain. This group was founded in 1979 and is called SEED (Sharing Experience in Engineering Design). The addresses for reaching SEED are:

For publications contact:
Publications Officer
SEED Ltd
P.O. Box 59
Loughborough
Leicestershire, LE11 0FS
Great Britain

The SEED Program is centered at
Design Centre
School of Engineering
Hatfield Polytechnic
P.O. Box 109
Hatfield, AL10 9AB
Great Britain

SEED's aims are:

* To encourage the informal sharing of experience in engineering design education.
* To facilitate the viewing of various design teaching departments.
* To provide a forum for ventilation of matters of concern in design education.
* To represent the collective and informed view of members in the pursuit of a better understanding of design and improvement in the quality of design education.

Among their publications are two compendiums of design projects that can be used with this text. There are a total of 44 projects that span different design disciplines. Each project is described in a two to four page narrative that includes: other engineering disciplines required for solution; sources of material; suggestions for grading and lectures; and estimated resources required. Additionally, other SEED publications give suggestions on the preparation for teaching design courses; cost estimating, communications, quality and reliability and specification development. Although the content of these publications is not extensive, they are worth the nominal fee SEED charges for them.

APPENDIX A. SAMPLE SYLLABUS

The following syllabus was used for a ten week Junior course at Oregon State University in 2008 (using the 3rd edition of the book).

ME 382: INTRODUCTION TO DESIGN
Fall 2008
Covell 221 for Lectures and Rogers 228 for Design Studio

Instructors

Professor David Ullman Office: Rogers Hall 416 Email: ullman@engr.orst.edu Phone: 754-3609 Office Hours: M 11:00– 12:00 or by appointment	Professor Irem Tumer Office: Rogers Hall 418 Email: irem.tumer@oregonstate.edu Phone: 737-6627 Office Hours: W 2:00-4:00

Class Hours

Lecture: MWF 12:00 - 12:50 PM (Section 001), 1:00 - 1:50 PM (Section 002)
Design Studio: TR 8:00- 9:50 AM, 10:00-11:50 AM, 12:00- 1:50 PM, 2:00-3:50 PM

Text

The Mechanical Design Process, David G. Ullman,

Course Objective

The objective of this course is to provide a team project-based, hands-on discovery experience of developing prototype products through a well-organized engineering design process including planning, problem definition, concept design, product design/realization, and testing. Design processes and methods are introduced through the Lectures; the processes and methods are applied in a design project in the Design Studio. Achieving the course objective will be measured through how well the students attain the following course learning outcomes.

Course Learning Outcomes

By the completion of this course, students must demonstrate the ability to:

1. Apply Gantt Chart techniques to identify project deliverables and make a 10-week work plan for a small-scale engineering design team project
2. State and illustrate the quality function deployment (QFD) method by using QFD to define an open-ended engineering design problem
3. Generate and evaluate conceptual design solutions using functional analysis and prototype testing given a design problem definition
4. Produce a product that meets functional requirements
5. Produce a product with originality, regulatory, and aesthetic considerations
6. Perform as part of an engineering design team

Design Project – MARS ROCKS

This is the project developed by American Society of Mechanical Engineers (ASME) for the 2009 ASME

Student Design Competition. A design problem description is available at the website:
http://www.asme.org/Events/Contests/DesignContest/Student_Design_Competition.cfm

An additional rule is being added to the contest for this course. The maximum that can be spent on off-the-shelf parts is $100/team. All prices are fair-market-value. New parts or components are considered at the price you paid for them. If there is a widget in your little brother's toy box you want to use, then its value on E-bay or other auction must be used.

Grading

Grading will be based on:

25% - individual homework
20% - individual design notebooks
20% - product development report (teamwork)
10% - design reviews (teamwork)
15% - field test results (teamwork)
10% - subjective evaluation (teamwork)

Total 100%

Each of the graded items is described below.

I. Individual Homework (Document A1-A26, see VI for their descriptions)

Due the Monday following the assignment at the beginning of class. The homework you turn in each week will be a photocopy of the individual entries in the design notebook; it is your responsibility to make sure that the photocopy is readable. The sequence of doing homework and record keeping in design notebook is: you read the material and do the assignment as part of your record keeping in your design notebook; then photocopy the assignment parts as homework to turn in. Your name and group number must be on each homework.

Note: You turn in the homework on Monday and, during your lab on Thursday you discuss the topics and reach team agreement on the results. Documentation of the team agreement becomes part of the team's Product Development Report (see III for description).

II. Individual Design Notebook

You are required to keep a permanently bound 8.5" x 11" design notebook for use in this course (this is a common practice for professional engineers in many industrial companies). All work concerning the design project will be entered into this notebook. The entries may include all individual homework, design ideas and reflections, teamwork discussion/results, design studio exercises, sketches, tables, and other contents that are closely related to the design project. Your name and group number must appear on the cover of your design notebook. Every page in the notebook must be numbered in ink at the beginning of the term. No pages can be removed and each page must be dated and initialed when used. In other words, everything you do on the project is included in the notebook. It is suggested that you use a spiral bound quadrille notebook and staple in pages as needed.

Each notebook will be collected at the end of the term and graded on the number of "quality entries" it contains. Typical examples of a quality entry include: a significant sketch or drawing of some aspect of the design; a listing of functions, ideas, or other features; a table such as morphology or decision matrix; or a page of text. Entries that are unintelligible are not "quality entries".

Note: do not use your design notebook for recording lecture notes. The lecture notes will not be counted as entries.

Notebook grading will be:

grade of 100% for 60 or more quality entries
grade of 95% for 55-59
grade of 90% for 50-54
grade of 85% for 45-49
grade of 80% for 40-44
grade of 75% for 35-39
grade of 70% for 30-34
grade of 65% for 25-29
grade of 60% for 20-24
grade of 55% for <20

Note that padding is obvious and not counted!

Your final entry in the design notebook will be at least one-page or more to reflect your design process, product performance, teamwork, your contest experience, and what you have learned from it. This is required.

III. Product Development Report (include Documents B1-B4, see VI for description)

This is a self-contained, well-written report summarizing the design process and team project. This file contains the TEAM results of the design process and product. Document B1-B4 must be included in this report. It is highly recommended that each team keep a single file of the team results along the product development process from earlier on during the term. At the end of the term the team will refine this file into a Product Development Report. The complete report should contain at least the following:

- Executive Summary (a picture of your product is required)
- Introduction
- Team results for the 32 items listed on the previous pages.
- Discussion of prototypes and final design including photographs
- Evaluation of field test
- Conclusion

The Product Development Report will be graded on its completeness of all the above items, clarity of explanation/justification/discussion on your design decision for each step, and writing quality. Due time: 11am, December 8th, 2008, at ROG418. An example Design Report Format can be found on the Blackboard. You do not need to follow this, but it gives some good ideas.. The grading template for the product development report is:

ME 382 Design Project: Product Development Report Grading Sheet

Team Number _______________ Date __________________

Executive Summary	**(max 2)____**
Introduction	**(max 1)____**
Problem Appraisal	**(max 4)____**
Conceptual Design	**(max 4)____**
Product Design	**(max 4)____**
Drawings	**(max 4)____**
Discussion of Prototypes	**(max 3)____**
Evaluation of Field test	**(max 2)____**
Conclusion	**(max 1)____**

Team Grade Total (max 25) _______________

IV. Subjective Evaluation

The subjective evaluation will be performed by the evaluation team from 12:00 - 5:00 PM on Thursday, December 4th, 2008. All the teams must place their products in Rogers Hall 228 by 12:00 PM. The grading template for subjective evaluation is:

ME 382 Design Project: Subjective Evaluation

Team Number ______________ **Date** _________________

Craftsmanship (3) ____
Compliance (2) ____
Originality (2) ____
Aesthetics (2) ____
Simplicity (1) ____

Team Grade Total (max 10) _____________

V. Field Test (announced broadly and open to general public)

The field test (ME382 Design Contest) will be held at 6:00 PM Thursday, December 4th, 2008, at Milam Auditorium. The teams can pick up their products at Rogers Hall 228 at 5:00 PM and transport them to Milam. Grading will be based on how your team places with first place receiving 100% and last place 60%. This event is open to the public.

VI. Description of the Required Design Process Documents

A. Documents that will be assigned as **individual homework** and thus be part of the notebook. Specifics about the Assignment are on the Blackboard in the folder labels "Homework Assignments". Many can be completed using pre-formated templates. These are labeled with a * and are in the Templates Blackboard folder.

i. Project Appraisal and Preparation Phase

Week 1: *Planning the Project*

A1. Task Titles, Objectives of each Task, Deliverable and Metric for each Task, Personnel Required for Each Task, Time Required for Each Task, all part of Project Plan Template *
A2. Schedule of Tasks
A3. Team Contract * and Personal Problem Solving Dimension *

Week 2: Understanding the Design Problem

A4. Description of Customers
A5. Customer's Requirements
A6. Weighting of Customer's Requirements
A7. Competition's Benchmarks Versus Customer's Requirements
A8. Engineering Requirements
A9. Competition's Benchmarks Versus Engineering Requirements
A10. Engineering Targets

ii. Conceptual Design Phase

Week 3: *Concept Generation*

A11. Functional Decomposition
A12. Function-Concept Mapping/Morphology *

A13. Sketches of Overall Concepts

Week 4: *Concept Evaluation*

A14. Technology Readiness Assessment
A15. Go/no-go Screening
A16. Decision Matrices to Determine Best Concepts
A17. Analysis, Experiments and Prototypes Supporting Concept Evaluation

iii. Product Design Phase

Week 5: *Product Generation*

A18 Analysis/Experiments and Prototypes – Test Report*
A19 Usable Off-the-Shelf Products (COTS)
A20. Shape Development Driven by Function (Individual Layout Drawings)
A21. BOM*

Week 6: *Product Evaluation*

A22. Comparison to Engineering Requirements
A23. Functional Changes Noted- Change Order *
A24 Analysis, Experiments and Prototypes Supporting Product Evaluation

Week 7: *Product Evaluation Continued*

A25. Design for Assembly Evaluation DFA*
A26. Cost Evaluation – Plastic Part Cost Calculator*, Metal Part Cost Calculator*

B. The following **team documents** are done by the team and are a part of the **product development report**. They are not counted as part of the design notebooks.

Final Product Documentation

B1. Layout Drawings
B2. Detail Drawings of Manufactured Parts
B3. Parts List (Bill of Materials)
B4. Assembly Sequence Instructions (optimized)

The drawings must be signed by the instructor before building.

VII. Design Review During the 4th and 7th week Design Studios you will have a Design Review. At these times you will present your team's effort to date to a panel that consists of Professors Ullman and Tumer, and other professional engineers from the faculty and industry. A Team Health Inventory* will be submitted independently by each team member at the beginning of the Review.

VIII. Teamwork Grade Adjustment Based on Team Evaluation

To make grading of team produced material fair, the team project grades will be corrected for each student with a weighting factor. This factor will be developed through each team member's confidential evaluation of all members in the team. Each member of the team will evaluate every member of the team (including themselves) for the percent of his/her contribution to the team project. The evaluations will be averaged by the instructor to find each student's contribution and the weighting factor made proportional to it.

Teamwork Contribution Evaluation Form

Team Number ________________ **Date** ________________________

Name	**Concept (%)**	**Analysis/ Testing (%)**	**Building (%)**	**Report (%)**	**Total Contribution to Teamwork (%)**

ME 382 Class Schedule

Time	Lecture	Reading	Assignment	Lab (including design studio)
Week 1 9/29 – 10/03	Understanding the Design Process; Project Planning; Product Development Team	Chapters 1-5	- HW1 (due 10/06) - Get familiar with the product development process - Be a team player - Transit to "Open-ended Problem Solving" practice ahead	-Team composition - Team building exercises - Make an initial team project plan
Week 2 10/06 - 10/10	Design Problem Appraisal	Chapter 6	HW2 (due 10/13)	- Understand and define the design problem - Modify the team project plan
Week 3 10/13 - 10/17	Concept Generation Function Decomposition	Chapter 7	HW3 (due 10/20)	- Practice visual thinking & sketching skills - Brainstorm on functions and concepts
Week 4 10/20 - 10/24	Concept Evaluation Decision Making	Chapter 8	HW4 (due 10/27)	**<u>Design Review 1</u>** - Build & Test concept prototypes - Analysis
Week 5 10/27 - 10/31	Product Generation Drawings	Chapter 9	HW5 (due 11/03)	Proof-of-concept prototypes due
Week 6 11/03-11/07	Product Evaluation Robust Design	Chapter 10-11	HW6 (due 11/10)	- Test prototype(s) - Analysis - Decide on one prototype for product
Week 7 11/10 - 11/14	Design for Manufacture & Assembly	Chapter 12, Appendix D	HW (due 11/17) Team Documents B1 – B4	**<u>Design Review 2</u>** - Ready-to-build product due on paper - Build & Test product
Week 8 11/17 - 11/21	Design for Product Life Cycle	Chapter 12	Build &Test product	Build &Test product
Week 9 11/24 - 11/28 (Thanksgiving)	Real World Product Development Examples	Handouts	Build &Test product	Build &Test product
Week 10 12/01 – 12/05	Contest Preview and Post-mortem	None	- December 4th, 12:00 p.m., products impounded at R228 for subjective evaluation - December 4th, 5:00 p.m., pick up products at R228 - December 4th, 6:00 pm, Field Test starts, Milam Auditorium - December 8th, 11:00 a.m., turn in Notebooks and Product Development Report together to Prof. Tumer at R418	**<u>Field Tests</u>** - Clean up the shop (mandatory)

APPENDIX B. THE COMPANY PROCEDURE BULLETIN

This bulletin has been used to direct the course in the past. It was developed from an actual company procedure bulletin and gives another layer of realism to the course.

THE COMPANY PROCEDURE BULLETIN

SUBJECT: Product Development Procedure
ISSUED BY: David Ullman
DATE ISSUED: March 88: REVISED: 89, 90, 2008

1.0 **SCOPE**

1.1 This document establishes the procedure and responsibility for product development within The Company, starting from product idea to production release. This document clarifies responsibility and goals at each phase of product development and establishes the contents of a Product Development File.

1.2 This procedure acknowledges that any task pertaining to the development of a new product, when authorized by the CEO (Chief Executive Officer: here, the faculty member) who issued this procedure, is a management directive to take appropriate and necessary action.

2.0 **PRODUCT DEVELOPMENT ORGANIZATION AND TERMINOLOGY DEFINITION**

2.1 The **organization of the Product Development Procedure** is outlined below. The process begins with the initiation of an idea for a product and, upon approval (see details below), a project is organized to develop that product. The project will follow the phases outlined below and culminate in release to production. The phases are:

I. Establish Need
II. Problem Understanding Phase
III. The Conceptual Design Phase
IV. The Product Design Phase
V. Release to Production

2.2 **<u>Product Development File</u>**: As a part of this procedure, a Product Development File is established. This file will contain all documentation required in this procedure. Note that if a project is terminated at any point, the final entry to the Product Development File must be a Product Termination Memo detailing the progress to date and the reasons for terminating the project. The file is maintained by the Product Manager and Product Design Engineer (see below) in a single, three ringed binder. The Product Manager has the responsibility of keeping the file up to date at all times. On project termination, either due to release to production or for any other reason, the complete Product Development File is archived in the office of the CEO. All entries in the File must be dated and signed.

2.3 **CEO**: The CEO (Chief Executive Officer) has final authority, at idea initiation and after each phase of the project, to approve continuation, termination, or the reworking of any phase of the project. It is only with his/her signed approval that a project is guided through development.

2.4 **Product Manager**: The Product Manger is an individual appointed by the CEO from his/her staff for a particular product development. The Product Manager will, throughout the project, have the primary responsibility for the performance of the product development and conformance with the product needs. He/she is responsible for the Product Development File.

2.5 **Product Design Engineer**: The Product Design Engineer is an individual appointed by the CEO from his/her staff for a particular product development. The Product Design Engineer will have primary responsibility for the design of the product, to release to production (assuming the product reaches production).

2.6 **Designer/drafter**: The Designer/drafter is responsible for the documentation of the design. This includes all drawings of the design, parts lists, and Product Changes Notices (PCNs). He/she is also to assist of the Product Design Engineer in the development of the design.

2.7 **Manufacturing Manager**: The Manufacturing Manager is responsible for assurance that the design is manufacturable. Additionally, s/he is responsible for developing Process Instructions for the assembly of the device. If manpower is limited, then the duties of the Manufacturing Manager will be combined with those of the Designer/drafter.

2.8 **Design Review Meeting**: At the end of each phase, or more often if deemed necessary, a design review meeting(s) will be called by the Product Manager, involving the CEO, the Product Design Engineering, the Designer/drafter and the Manufacturing Manger. The Product Manager, supported by the Product Design Engineer, will formally present results to the attendees and conduct the meeting(s). The objective of the meeting(s) is to determine the project's worthiness of continuing to the next phase, identifying weaknesses and suggesting how to resolve them, or deciding to terminate the project. Additionally, a detailed plan for the next phase of work must be presented at this meeting. This plan will include a schedule developed by the responsible parties for each task. In this way, the magnitude of the project, in terms of manpower and facilities requirements, can be judged prior to approval to continue. The project will only continue to the next phase, terminate, or iterate back to correct weaknesses upon the signed approval of the CEO. As detailed below, this approval becomes part of the Product Development File.

3.0 **ESTABLISH NEED**

3.1 Ideas for new products will be submitted in writing to the CEO either by the staff or by outside parties. The CEO will have responsibility for determining if the idea warrants evaluation. If it is deemed worthwhile, the CEO will appoint a Product Manager, a Product Design Engineer, a Designer/drafter and a Manufacturing Manager for the proposed product. If necessary the duties of the Designer/drafter and the Manufacturing Manager can be combined. With these appointments, the project will begin. The statement of the need for the product becomes the first entry into the Product Development File.

4.0 **THE PROBLEM UNDERSTANDING PHASE**

The result of the problem understanding phase will be a clear indication of the product's requirements and performance measures.

4.1 **Determination of the Design Requirements**

The Product Design Engineer, in consultation with the others working on the product, will be responsible for:

- Developing a full set of design performance requirements.
- Identifying the capabilities of the competition
- Determining the available technical skills and resources
- Determining the available manufacturing resources and capabilities (help from Manufacturing Manager is expected here)

A report on the above items titled "Product Design Requirements" will be developed and entered into the Product Development File.

4.2 **Performance Measures Development**

The Product Design Engineer, in consultation with the others working on the project, will be responsible for:

- Managing the development of the performance measures
- Insuring throughout the remainder of the project that these measures can be met or clearly identifying why they can not be met in a written memo to the CEO.

A report on the above items titled "Performance Measures Development" will be entered into the Product Development File.

4.3 **Program Plan Development**

The Product Manager, supported by the rest of the staff; will prepare:

- Developing a program plan - schedule and manpower for the following areas:
- Engineering
- Design and Drafting
- Manufacturing
- Field test plan

This plan will include all phases of the product development through release to production. To be complete, each step in the development must be considered a separate task with a specific, measurable goal. These tasks will include not only the phases described in this document, but all experiments or analysis needed to accomplish the design. It will be updated as required during the project, but only upon approval by the Product Manager or higher authority, and with written communication to all parties. The "Program Plan" will be entered into the Product Development File.

4.4 **Product Idea Initiation Design Review**

Upon completion of the above specifications and plans, a Design Review Meeting will be held. The results of this meeting will be:

> Either: Approval to continue - "Pre-design Phase Completion Memo" authorization to continue with the Conceptual Design Phase.
>
> Or: Continuation of Product Idea Initiation Phase - instructions to go back and improve the plans and/or requirements and/or measures.
>
> Or: Project termination - "Project Termination Memo."

Whichever document applies will be signed by the CEO and become part of the Product Development File.

4.5 All documentation generated will be entered in the Product Development File under the title of Pre-design Phase Documentation. This will include at least:

- Product design requirements
- Performance measures
- Program plan

5.0 **THE CONCEPTUAL DESIGN PHASE**

5.1 The result of the design phase will be a set of concepts that meet the performance requirements. The Product Design Engineer will be responsible for developing these concepts. He/she will be supported by the Manufacturing Manager, Designer/drafter, and Product Manager.

5.2a **The Product Design Engineer will be responsible for:**

- Establishing functional requirements - what the product does
- Developing ideas to meet the functional requirements

5.3b **The Designer/drafter will be responsible for**:

- Developing sketches of ideas

5.4 All documentation generated in this phase will be entered into the Product Development File under the title of "Conceptual Design Documentation". This will include at least:

- functional requirements
- ideas to meet functional requirements
- sketches of ideas

6.0 THE LAYOUT DESIGN PHASE

6.1 The result of the layout design phase will be a single design concept for the product. The Product Design Engineer will be supported by the Manufacturing Manager, Designer/drafter, and Product Manager.

6.2 Deviations requiring significant changes in the product design requirements or plan should be discussed in a Design Review Meeting (2.6). Minor changes require only the approval of the Product Manager. It will be the responsibility of the Product Manager to determine if a Design Review Meeting is warranted.

6.3a **The Product Design Engineer will be responsible for:**

- Developing Concepts for Evaluation

6.3b **The Manufacturing Manager will be responsible for:**

- Establishing the manufacturability of concepts

6.3c **The Designer/drafter will be responsible for:**

- Producing drawings of the final layout

6.3d **The Product Manager will be responsible for:**

- Selecting the final concept

6.4 All documentation generated in this phase will be entered into the Product Development File under the title of "Layout Design Documentation." This will include at least:

- Concepts evaluated
- Evaluation criteria used
- Results of the evaluation, the final concept
- Layout Drawing of the concept

7.0 THE DETAIL DESIGN PHASE

7.1 The result of the detail design phase will be drawings for a working prototype of the product. The Product Design Engineer will be supported by the Manufacturing Manager, Designer/drafter, and Product Manager.

7.2 Deviations requiring significant changes in the product design requirements or plan should be discussed in a Design Review Meeting (2.6). Minor changes require only the approval of the Product Manager. It will be the responsibility of the Product Manager to determine if a Design Review Meeting is warranted.

7.3a The Product Design Engineer and Product Manager will be responsible for:

- Decisions concerning parts manufacturing
- Development of testing methods and procedures for components, subassemblies, and finished parts
- Generating patent applications

7.3b The Manufacturing Manager will be responsible for:

- Establishing service requirement - maintainability
- Generating manufacturing details
- Determining any special tooling required

7.3d The Designer/drafter will be responsible for:

- Generating a parts list - Bill of Material
- Establishing the assembly procedure
- Developing drawings of manufactured parts and assemblies

7.4 Upon completion of the above tasks, a Design Review Meeting will be held. The results of this meeting will be:

Either: Approval to continue - "Design Phase Completion Memo:

Or: Continuation of the Design Phase, or return to the Pre-design Phase

Or: Project termination - "Project Termination Memo."

Whichever document applies will be signed by the CEO and become part of the Product Development File.

7.5 All documentation generated in this phase will be entered into the Product Development File under the title of "Detail Design Documentation." This will include at least:

- the parts list
- drawings of manufactured parts
- assembly drawings

8.0 THE PRE-PRODUCTION PHASE

The goal of this phase is to complete the development of the product prototype and release it to production.

8.1 **Field test prototype construction:** As per the plan established in paragraph 4.3, a field test prototype will be constructed. Any deviation from the approved design will require a product change notice PCN (section 10.0).

8.2 **Field testing:** The Product Manager is responsible for establishing a program to field test the prototypes in a user atmosphere. The Product Design Engineer will maintain responsibility for all technical aspects of the tests. Tests should provide conclusive indication that the product is acceptable for use as designed, or show the specific areas for design/quality improvements. Detailed results of the field tests will be a part of the Product Development File and Titled, "Field tests results." These will include a discussion of all favorable or unfavorable results of the field tests.

8.3 Upon completion of the above tasks, a Design Review Meeting will be held. The results will be:

Either: Approval for release to production by the CEO - "Approval for Release to Production Memo."

Or: Continuation of the Pre-Production Phase

Or: Project termination - "Project Termination Memo."

CEO approval for release to production implies that the product is considered ready for production.

8.4 All documentation generated in this phase will be entered into the Product Development File under the title of "Preproduction Phase Documentation." This will include at least:

- field test results
- product change notices

9.0 **THE RELEASE TO PRODUCTION**

Upon completion of the pre-production run approval for release to production must be made by the CEO. After this approval, the product is the responsibility of the Product Manager and Manufacturing. Further Engineering support is provided only through an Engineering Change Request Final approval for shipping production units must be given by the CEO.

10.0 **PRODUCT CHANGE NOTICE**

Subsequent to the "Design Phase Completion Memo" (section 5.5) all design changes must be noted on a Product Change Notice (PCN). Each PCN will be on a separate page in the product development file. It will include at least: what the change is, why it is needed and what alternatives were considered.

Problem Understanding Phase Completion Memo

Group # __________
Date ____________

This group has completed all requirements of the predesign phase. I have reviewed their Product Development File and found the following:

* Product Design Requirements
* Performance Measures
* Program Plan

I approve these documents and the initiation of work in the Conceptual Design Phase.

____

David Ullman
CEO and Professor

Conceptual Design Phase Completion Memo

Group # __________
Date ____________

This group has completed all requirements of the design phase. I have reviewed their Product Development File and found the following:

* functional requirements
* ideas to meet functional requirements
* sketches of ideas

I approve these documents and the initiation of work in the Layout Design Phase.

____
David Ullman
CEO and Professor

Layout Design Phase Completion Memo

Group # _________
Date ___________

This group has completed all requirements of the design phase. I have reviewed their Product Development File and found the following:

* Concepts evaluated
* Evaluation criteria used
* Results of the evaluation, the final concept
* Layout Drawing of the concept

I approve these documents and the initiation of work in the Detail Design Phase.

____
David Ullman
CEO and Professor

Detail Design Phase Completion Memo

Group # _________
Date ___________

This group has completed all requirements of the design phase. I have reviewed their Product Development File and found the following:

* the parts list
* drawings of manufactured parts
* assembly drawings

I approve these documents and the initiation of work in the Preproduction Phase.

____

David Ullman
CEO and Professor