

## **Designing Across the Curriculum: Linking Sophomores to Mechanical Engineering**

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### **Abstract**

The sophomore year in traditional engineering programs rarely includes formal course work in engineering design. Considering the broader philosophy of Design Across the Curriculum (DAC), the sophomore year, however, can be used to reinforce meaningful design activities experienced as a freshman, and to prepare students for upper level design course work and eventual practice.

In preparing its curriculum, as a newly chartered program in Idaho, the Mechanical Engineering faculty at Boise State University has incorporated a three credit hour course entitled Mechanical Engineering Design in the sophomore year. Blending considerations of design theory, design methods, design automation, materials & manufacturing, the faculty team has prepared and has executed the 16 week curriculum during the 1997 spring semester.

This paper describes course details including: objectives, topics covered, team teaching approach, weekly class format, prerequisites, activities pursued, student grading, infrastructure, resources, faculty team planning, outcomes assessment techniques and results.

### **1.0 Design Across the Curriculum**

BSU's ME program was recently chartered by the state of Idaho (1995). During the Spring of 1996 the faculty designed the 131 semester credit hour, four year curriculum. A variety of considerations included the proportion of courses in mathematics, sciences, humanities, arts, and social sciences. The existing and future demand for engineers in Boise, Southwest Idaho, and the Northwest region was deliberated as well as the quality of education to be delivered.

While ABET specifies minimum criteria for four year engineering programs, it is the desire of Mechanical Engineering faculty to meet and exceed these requirements. Namely, to develop & deliver appropriate, high quality and comprehensive course work and at the same time, exceed the minimum requirements for ABET accreditation.

Design, being central to the practice of engineering, was given significant consideration, especially how to integrate design across the curriculum (DAC). The essence of DAC is somewhat captured in the following phrase:

“...Design cannot be taught in one course; it is an experience that must grow with the student's development.” (*1996/97 Criteria for Accrediting Programs in Engineering in the United States*, section IV.C.3.d.(3)(d), ABET, Inc.)

A draft policy on Design Across the Curriculum was prepared and distributed to the faculty in August 1996. A revised draft, specific to the ME program, is currently under review for

adoption. In it, the underpinning design philosophy encourages design throughout the ME curriculum and involves an appropriate breadth & depth of design knowledge, methods, and skills, to be taught in most of the required ME courses as presented in Table 1.

To help us develop course content, a list of expected design skills for graduating ME students was prepared and is presented in Table 2, Mechanical Engineering Design Skills. It is anticipated that we will be able to help students learn these skills by endeavoring to incorporate appropriate design activities, homework, projects, and other learning modules in each course.

By using the progressive breadth & depth approach, we are, in effect, using just-in-time learning, wherein each student is introduced to the right topic or tool at the right time, that “grow(s) with the student’s development” (ibid).

### ***Design Courses in Mechanical Engineering***

Most, if not all, ME courses will ultimately incorporate appropriate design aspects. Some courses, however, have significant design content, and are listed in Table 3. The freshman course, entitled Engineering Fundamentals, Analysis & Design (EN180), includes two-hour labs and one lecture hour each week. One lab is for computer applications & problem solving and the other for design activities. The course culminates with a four week design contest, in which groups design and build a small remotely controlled machine to compete against other teams. The junior courses relate to component design. The Senior course, entitled Thermal & Fluid Systems Design (MX424) deals with thermal component design & process design. The Senior Design Project is the capstone design experience typically implemented in small teams with local industrial sponsors.

The sophomore Mechanical Engineering Design (MX280), is somewhat new, however, when compared to traditional Mechanical Engineering curricula. Note that it fits snugly between the Freshman & Junior years, developing design topics, fully within the skill mix of entering students.

Professors Bunnell, Eggert & Tennyson met weekly during the fall of 1996 to design the details of the course namely we prepared detailed learning objectives, lecture topics, laboratory activities, homework, projects, computer software, textbooks and grading schemes, to arrive at our first cut at a syllabus for Spring 1997. These and other details of the course are presented in the next sections.

## **2.0 Designing the Course:**

### **2.1 Design Specifications for MX280**

Design can be defined as a **decision making process**, *to determine the shape, configuration, size, types of materials and manufacturing processes* used for typical machine elements and assemblies. By equipping sophomore engineering students with an appropriate mix of design skills and tools, they should be able to make better decisions in their engineering practice as well as in their follow-on courses required in the undergraduate degree.

We, therefore, set out to interweave three main threads into MX280: 1.) design methodology,

2.)design automation, and 3.)materials & manufacturing processes. We developed related specific and detailed objectives for each as shown in Table 4. Specific Objectives for MX280 Mechanical Engineering Design. These became our design specifications or “functional requirements”, that the course would fulfill. As Steve Tennyson puts it, “after completing the course, the student should, at least, have a general idea what mechanical engineering design is about.”

Entering student skill mix can be assessed, somewhat, by examining the prerequisite courses which are: EN180 Engineering Fundamentals, Analysis & Design; EN108 Engineering Graphics; Math 205 Calculus & Analytical Geometry (calc II); and PH211/212 Physics I. Note that although desirable, Materials Science & engineering Statics are not prerequisites.

## **2.2 Course Concepts, Configurations, & Parameters**

Many, many alternative concepts, configurations and parameters were deliberated during the planning stage. We ultimately decided upon the following:

### ***Configuration:***

The following time & day configuration was selected to approximate the proportion of desired lab and lecture time needed to achieve our objectives. The course bears three semester credit hours.

Monday	50 min lecture,
Wednesday	2 hr 50 min lab, and
Friday	50 min lecture.

### ***Texts:***

The backbone, or fundamental resource material, of any course is its textbook. We selected *Engineering Design and Design for Manufacturing*, by Dixon and Poli as our design methods text and *AutoCAD Release 13 for Windows*, by Shawn Lockart, as our CAD reference. While Dixon’s book is conventionally used at the Junior year or above, chapters can be judiciously selected. We assigned chapters 1-10, 13, 14, 17, 18, 22 & 23, out of 24 total, leaving the specialized chapters on design for manufacturing for later courses.

### ***Lecture Topics:***

The lecture topics dovetailed with the assigned reading. Dixon’s book comprehensively discusses contemporary design theory & methodology using well illustrated figures and many examples. In-class, collaborative learning group exercises and standard lectures were used in the 50 minute class periods covering the following topics

1. Introduction to Mechanical Design
2. Product Realization Process
3. Three Dimensional Modeling
4. Manufacturing for Designers
5. Specifying Designs
6. Synthesizing Alternatives
7. Evaluating Design Concepts
8. Selecting Materials

9. Configuration Design
10. Parametric Design
11. Design Optimization
12. Rapid Prototyping
13. Documentation / Communication
14. Engineering Economics

***Laboratory Activities:***

The mid-week lab is designed for hands-on activities which integrate the lecture topics including a design project using computer applications, artifact design & build using basic machine/hand tools, simulation modeling, and rapid-prototyping.

1. Solid Modeling: “Tape dispenser”  
Autocad/R13, 3 weeks
2. Design & Build: “Can Crusher”  
Shop Tools / materials, 3 weeks
3. Parametric Design “Mountain Bike Suspension”  
Excel & Working Model, 2 weeks
4. Optimal Design: “Beer Can”  
Excel, 1 week
5. Rapid Prototyping: “Crank”  
Laminated Object Modeling / Schroff Development, 2 weeks

***Grading:***

We established the following grading scheme to evaluate student learning. While somewhat coarse, it provided us the flexibility to make minor adjustments during the course, especially for the first time taught.

- |                        |     |
|------------------------|-----|
| 1. Homework & Projects | 50% |
| 2. Tests I, II, III    | 30% |
| 3. Final Exam          | 20% |

**3.0 Evaluating the Course Design**

Did we achieve our objectives? Did the team teaching approach work? What problems did we have? Did the students get inspired about mechanical engineering?

***Tests & Project Grades:***

The three tests were “short” answer, fill-in-the-blank, true/false, matching type tests. The average scores for tests I, II, & III were respectively 82.3, 82.6, 76.8% with standard deviations of 9.4, 8.3, 10.0%, indicating that the students successfully learned the concepts, as tested by the questions. The final exam is cumulative, worth 20% of the course grade. Similar scores are expected, however. Project grades have also been satisfactory. Two students were given extra-time to complete the first solid-modeling exercise, however.

***In-Lab Survey:***

We have a number of improvements in mind already, which is only natural, since the course had never been taught, and because we were using software & textbooks never used by us before.

We desired, however, to include student feedback regarding suggested changes in this report. An in-lab 3 minute survey was conducted the 14<sup>th</sup> week, asking the students to list “the three changes or refinements that they would like to see in the course for the future”. Suggestions included: reducing the reading, having more “hands-on” work (build / manufacture), lab work should be complete-able during the 3 hour period, “reduce the amount of vocabulary”, have *more* Autocad, have *less* Autocad, increase the “contiguity”, and “build on the subjects”. Also, and somewhat surprisingly, the students felt that one teacher would have been better for the course. That there should be “better communication between the professors”, that they “sensed some friction,” and that one professor “would allow the class to be more focused with a more reasonable work load.” The university course evaluation forms will be completed in two weeks. They will be factored into the course re-design, along with the final exam results and other assignments.

### ***Team Teaching Approach:***

During the semester, we met weekly for about an hour. We reviewed the prior weeks lectures and labs, noting some possible changes we might wish to include in the future. We discussed the upcoming week’s lectures and lab, who was responsible, what was to be done, how it was to be accomplished. In the earlier weeks, we also refined and detailed the projects coming later in the semester, those that were merely sketched-out at the beginning of the semester. Needless to say, when you put three teachers in the same meeting together they may disagree, once or twice. We had our disagreements too. But, by the end of the meeting, we knew who was going to do what, when and why. A small problem, however, is that Eggert & Tennyson are design “junkies,” each having over two decades of interest in following & developing design methods. This strong interest tended to extend some of the team teacher meetings beyond their original objectives and time limits. Also, the team teachers sat in on each of the others lectures during the term, occasionally asking questions, due to interest, much like a student would. It appears that the students perceive faculty questions and faculty disagreement as a distraction rather than as an intellectual pursuit of knowledge. One improvement to the team teaching approach would be to designate a faculty-in-charge-of-course for the students and to invite “guest lectures.” Or to explicitly discuss “disagreement & conflict resolution” with the class.

### ***New Learning Assessment Techniques:***

Tests, exams, surveys, and course evaluations are some of the objective and subjective measures of learning, along with written homework and project reports. Currently, they compose the principle set of assessment tools. Mechanical engineers consider 3D features and shapes in many of their decisions. The ability to “visualize,” “in the mind’s eye,” may not be easy to assess. But yet, that ability is valuable. And lastly, surveys & “attitude” based course evaluations must be judged and weighed appropriately. Recall the market research parable about the researcher who asked a potential customer, “would you buy sample “A” or “B?” The customer said he’d buy neither, that he buys product “C” and is happy with it. Course development, therefore, should be based on what the *student does not on what he says*. Other assessment means, based on observation of student behavior, are being considered.

#### **4.0 Design Refinement of MX280**

During weekly meetings the instructors evaluated the previous week's efforts and outcomes in an attempt to continuously improve the course. Also, at the end of the semester, students completed the conventional course evaluation. The results were in agreement with our informal assessments. Additionally, over the span of the course students have had the opportunity to offer suggestions for improvement in course structure, content, and presentation format. Many of their suggestions are in accord with what the instructors already had in mind; others suggestions have caused even a deeper rethinking about the course. The following is a description of additions and changes which are under serious consideration for the next course offering.

##### ***Textbook Reading Revisions***

Having “walked the walk,” we will revise the quantity and timing of the reading assignments to be more balanced over the semester. The initial weeks were somewhat overloaded. In addition, some sections could be more appropriately deferred to later courses.

##### ***Manufacturing Processes Tour(s)***

Arrange tours of commercial facilities to witness actual production operations by various manufacturing methods. Schedule these "live" demonstrations so as to coincide with classroom coverage of manufacturing methods. Allow students the opportunity to interview the production engineer at the conclusion of the tour to discuss what they have observed in relation to their course work. These tours should provide greater insight and understanding of the materials in this important portion of the course.

##### ***Design Practice / Dept / Firm Tour***

Arrange a tour of a commercial firm which employs current design methodology and design automation in the product development process. Schedule this tour near the terminus of the course after students have covered design methodology and design automation, and have had a chance to apply it themselves. At the conclusion of the tour allow students the opportunity to interview one of the firm's design teams to discuss what they have been presented in relation to their course work. This experience should add an interesting perspective to their course work.

##### ***Integrated Semester-Long Project***

Our original syllabus included an integrated five week project. Having underestimated some of the required effort, and extending some assignment deadlines, we decided to drop the last project. Next year we might form three or four person teams to pursue a semester long project which incorporates all major elements of the course. It could have “flexible” milestone deadlines and actually reduce some of the anxiety caused by overextended lab activities. The project would be to design a simple product with just a few parts. Results of the project are to be well documented report demonstrating that functional requirements of the product have been met, and that it could be manufactured in quantity. (Consideration should also be given to creating some form of a physical model.) As a part of their education, engineering students are expected to learn to work productively and cooperatively as team members on long term projects; sophomore design is the appropriate starting point. Besides, methods taught in this course for generating and evaluating design alternatives assume the existence of a project team.

### ***Integrated Prototyping & Design Refinement***

As design refinement and documentation of their semester long project, have each team rapid prototype a scale model of one part of their final design in order to verify the correctness of its three dimensional form. Currently, students have an introduction to classroom materials on rapid prototyping reinforced through a "hands on" demonstration exercise with an inexpensive system which "mimics" laminated object modeling - the JP System 5, a desktop layer cutting and manual assembly system by Schroff Development Corporation. A higher level of understanding and appreciation for this kind of system would be to work through the details of generating a model of their own design.

### ***Parametric Solid Modeling***

Introduce and implement a parametric solid-modeling CAD package which actively supports guided iteration methodology, and streamlines design documentation. One three hour lab activity, which used the software this semester, was encouraging. Solid modeling is now the accepted standard for representing machine part geometry. More powerful are parametric solid modelers in which part dimensions are treated as design variables, and interconnecting features between parts in a machine are linked by global parameters. Plans are to utilize one such package, Mechanical Desktop, now available for classroom instruction in the College of Engineering at BSU.

### ***Parametric Solid Modeling Coupled to Parametric Design***

Demonstrate the utility of incorporating parametric solid modeling into guided redesign during the parametric design phase. During this design phase numeric values for dimensions and tolerances are determined for each part through analytic procedures which provide estimates of the performance of trial designs. Trial designs are evaluated against design goals, and redesign and re-evaluation proceed as needed using guided iteration. Thus, a CAD package that can rapidly update any and all changes in geometry after each iteration will provide immediate support for visualization of results, and for checking form, fit, and interference.

### ***Geometric Dimensioning & Tolerancing***

Introduce the basics of geometric dimensioning and tolerancing per American National Standard Dimensioning and Tolerancing Y14.5M. Present examples such as positional tolerancing for maximum material condition, and provide sample parts with geometric features representing this tolerancing condition which can then be checked using supplied gaging equipment. The complexity and sophistication of modern designs require a precise interpretation of design intent; geometric dimensioning and tolerancing provides for this precise interpretation. Students need to know about this technique, and how it can be applied to avoid problems in product functionality, part manufacture, and measurement verification.

### ***Hands-On Scale Modeling***

The ability to "visualize" in three dimensions is developed, to some extent, in engineering graphics courses. But, it may also be the result of physically manipulating 3D objects having multiple features. In the past, engineering students typically built model airplanes, boats or full scale go-carts, roadsters and motorcycles. These avocational interests may have contributed to their "visualization" abilities. Today's students apparently have less interest, preferring their

computer games instead. Design activities or labs that involve building objects that can be handled, may be valuable in the development of this skill.

### 5.0 Summary

The ME curriculum at BSU has implemented a new, required sophomore course in design. Assessment measures indicate that the basic course design was satisfactory. Students have learned about design methods, design automation and materials & manufacturing methods related to design. The lecture-lab-lecture configuration worked, and the team teaching approach was do-able. But as is usually the case for new courses, the course will undergo some additional refinements as discussed.

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Year	Design Emphasis
Freshman	Design as a Process
Sophomore	Solving Open-ended Problems
Junior	Component & System Design
Senior	Capstone Design / Project

Table 1. Progressive Breadth & Depth Emphasis of Design Across the ME Curriculum.



**BASIC SKILL:** Understand & experience the **whole design process:**

- |                        |                       |
|------------------------|-----------------------|
| 1. formulate / specify | 4. optimize / iterate |
| 2. synthesize          | 5. present / document |
| 3. analyze & evaluate  |                       |

**DETAIL SKILLS:**

**1. problem formulation & function specification:**

- scope out the design problem
- determine what functions are important to the customer
- establish thorough design specifications (functional)
- determine applicable constraints (physical, social, ethical, economic)
- plan for the solution (of open-ended problems)

**2. synthesis:**

- generate alternatives for how specified functions are met (concept design)
- define applicable governing equations and analytical models
- resource use (corporate files, experts, library, networks)
- methods (brainstorming, inversion, checklists)

**3. analysis / evaluation:**

- modeling (mathematical, computer and/or experimental models)
- numerical and or physical experiments
- construction - basic production / manufacturing processes / tolerancing
- product/prototype testing

**4. optimization and design refinement:**

- determine feasibility of candidate designs (constraints satisfied?)
- establish figure(s) of merit for “best design”
- select best candidate from feasible candidates
- establish comprehensive/detail design attributes

**5. presentation/documentation**

- detailed design specifications, system descriptions, product specifications
- effective use of engineering terminology & symbolic/math communication
- graphical (drawings, sketches, diagrams, & charts)
- verbal/oral reporting

Table 2. Design Skills for Mechanical Engineering graduates at BSU

**Overall**

Understand and apply the whole design process,

**Design Theory & Methodology Objectives:**

1. recognize & articulate the design constraints
2. identify customer requirements, marketing decisions/issues.
3. develop engineering design specifications (vs prod. specs.) for typical design problems.
4. generate alternative forms (concepts) that meet specified functions
5. evaluate candidate concepts (before building & testing)
6. refine candidate designs using guided iteration and fundamental optimization techniques
7. recognize design decisions wrt patents, legal liability(safety), & ethics
8. define terms related to design

**Design Automation Objectives:**

1. implement spreadsheet models to evaluate & optimize candidate designs
2. solid model basic parts & features
3. graphically communicate design ideas effectively in 2D & 3D
4. assemble parts in 2D & 3D, i.e. assembly drawings.
5. parametrically solid model / intelligent parts & assemblies
6. dimension & tolerance a mechanical part wrt Mfg process.
7. proto-type simple parts
8. define terms related to design automation

**Manufacturing Processes & Materials Objectives:**

1. distinguish basic manufacturing processes, advantages & disadvantages
2. select basic manufacturing processes for specific design applications
3. select basic materials for specific design applications
4. operate a variety of hand tools
5. distinguish some basic machine tools & their uses
6. define terms related to materials & manufacturing processes

**Ancillary Objectives:**

1. work effectively in groups / teams
2. verbally communicate design data, issues, decisions etc.
3. build physical scale models / prototypes & conduct preliminary engineering tests

**Optional (time permitting)**

1. operate a few basic machine tools
2. produce a CNC milled prototype
3. geometric dimension & tolerance
4. size shafts / holes

Table 4. Specific Objectives for MX280 Mechanical Engineering Design

**Freshman Year**

EN180 Engineering Fundamentals, Analysis & Design

**Sophomore Year**

MX280 Mechanical Engineering Design

**Junior Year**

MX380 Kinematics & Dynamics

MX382 Machine Design

**Senior Year**

MX424 Thermal & Fluid Systems Design

MX480 Senior Design Project

Table 3. Design Thread in ME at BSU.