Teaching mechanical design to a large class: A report from Taiwan

Abstract

One problem widely existing in current mechanical design courses in Taiwan is that it is constraining with respect to manpower, facilities, and/or budget, to have mechanical design projects in the current large-class setting. This paper presents a course model dealing with this problem. The goal is to provide students the tools and environment to experience design. This model was quite successful when implemented in the Department of Mechanical Engineering, Yuan Ze University, Taiwan, where I teach a junior-level mechanical design course having more than one hundred students in two sections.

I. Introduction

“Mechanical Design” is a one-year, junior-level required course in most mechanical engineering departments of the universities in Taiwan. Students taking this course usually have just completed the major background courses in mechanical engineering (e.g., statics, dynamics, strength of materials, thermodynamics), with no formal training in engineering synthesis.

There is almost general agreement that using student projects is a good, even necessary, means to “teach” design. One important reason for using student projects in design courses is to provide students a means for “experiential learning.” Many aspects of design, such as problem solving, creativity, team cooperation, to name just a few, cannot be taught by lectures, textbooks, and problem sets. Students have to learn these aspects of design by actually doing design, experiencing design. Faste, Roth, and Wilde of Stanford University made a rather strong statement about design projects and design courses [1]: “We believe that
any course without student projects is not a design course. That does not mean such a course is bad or should not be offered, or that it is not of value to design education, we just mean it is not a design course. It certainly can be about design, but it is not a design course.”

The Accreditation Board of Engineering and Technology (ABET) of the United States has called for integrating the design experience across the engineering curriculum. The ABET evaluations of engineering programs review the integration of design content and practice throughout the curriculum, including introductory, intermediate, and advanced classes. ABET requires institutions to examine their present approach to design to be sure the design experience is a comprehensive and integral part of the education process [2].

However, engineering design education does not receive equal attention in the universities of Taiwan. In most Taiwan mechanical engineering departments, “mechanical design” is still viewed as just a regular, stand-alone course. It is usually not integrated with any other courses, and the resources available to the mechanical design course are no more than that to a regular lecture course, e.g., strength of materials. Therefore, one problem widely existing in current mechanical design courses in Taiwan is that it is taxing with respect to manpower, facilities, and/or budget to have mechanical design projects in the current large-class setting. A great portion of the junior-level mechanical design courses in Taiwan are still purely lecture courses instead of being project-based.

Extensive research has been done in the area of engineering design education. Subjects such as defining the goals and format of engineering design courses [2-4], different styles and approaches of teaching engineering design courses [5, 6], how to use design projects [7], how to assign students to groups for design projects and the dynamics of design groups [1, 8], to name just a few, have been carefully studied. But to the author's knowledge, few papers if any have been published specifically on teaching engineering design courses to a large class with limited resources, a very common situation here in Taiwan.

This paper presents a course model that attempts to address this problem. Section Two presents the results of a questionnaire that surveys the current situations of mechanical design courses in Taiwan. Sections Three and Four describe the course model in detail; then Section Five discusses the feedback from students experimenting with this model in the Mechanical Engineering Department, Yuan Ze University, Taiwan. Finally, Section Six gives a general discussion of the more fundamental issues regarding design education in Taiwan.

II. Junior-level mechanical design courses in Taiwan

To understand the current situation of the junior-level mechanical design courses in universities in Taiwan, a questionnaire was designed and distributed to all universities and four-year technical colleges. This questionnaire was specifically sent to professors who are
currently teaching a junior-level mechanical design course. A total of 42 questionnaires were sent out, and 34 (81.0 percent) responded.

According to this survey, in the universities in Taiwan, a typical size of the junior-level mechanical design class is 40 to 49 students (44.9 percent), and 38.8 percent of the design classes have a size of over 50 students. Moreover, 50.0 percent of the professors responding to the questionnaire are teaching two to three sections in the same semester. That is, half of the professors have more than one hundred students in their design courses in the same semester.

A rather surprising fact is that, only 40.0 percent of the mechanical design courses in Taiwan use design projects. Among the classes which do not have design projects, 44.4 percent have a required design project course in their senior year, 22.2 percent have an optional design project course in their senior year, while 33.3 percent do not have any other design project courses.

When asked about the possible difficulties of having design projects in their mechanical design courses, the professors' top three choices listed on the questionnaire were “lack of budget and proper environment” (72.7 percent), “the size of the class is too big” (66.7 percent), and “the professors do not have enough time” (45.5 percent). The professors also responded with several other difficulties that were not listed on the questionnaire, including “course time is not enough to cover the material and finish the projects” (12.1 percent), “manufacturing difficulties” (12.1 percent), “students are not willing to spend time on design projects” (9.1 percent).

It is also very interesting to know what subjects are being taught in the mechanical design courses. According to the survey, there seems to be no standard content for the junior-level mechanical design course. Ten subjects were listed on the questionnaire, and each subject was taught by at least 12.1 percent of the professors. Mechanical component design, which is a more “traditional” subject taught in the junior-level mechanical design courses, is taught by 93.9 percent of the professors. Other popular subjects include structural analysis (51.5 percent), design drawings and documentation (36.4 percent), and system design methodology (31.3 percent). The content of the mechanical design courses seem to be closely related to the specialty of the professor who is teaching it.

This questionnaire and the statistics of the answers to each question are listed in the Appendix.
III. Building a design tool box

I have taught a junior-level mechanical design course for five years. Each year I have two sections, with a total of more than one hundred students. There is only one graduate teaching assistant assigned to the course, and other resources are also quite limited. In the second year I taught this course, I started to develop a new course model for such a large class.

First the goal of the design course is defined. Instead of trying to define design, ABET [9] describes activities and processes that may be included in design. Design, therefore,

- Produces a system, component, or process to meet a specific need.
- Is an iterative process that utilizes decision making with economics and employs mathematical, scientific, and engineering principles.
- Includes some of the following: setting objectives, analysis, synthesis, evaluation, construction, testing, and communication of results.
- Has student problems that are often open-ended, require use of design methodology and creative problem solving, require formulation of the problem statement and an economic comparison of alternate solutions, and may require detailed system details.

From this description of design, a variety of possible goals for a mechanical design course can be generated. The goal our design course strives to achieve is simple and clear: to provide students the tools and environment to experience design, despite our limited resources. The design tools include engineering domain knowledge and design methodologies. By design environment we do not mean only a physical one. For us, a design environment provides proper design projects, design team organization, and proper supervision of the projects. The design experience we wish the students to go through during the course includes the problem solving process, creativity, and team cooperation.

In order to be able to experience design, the students must be given enough “design tools.” As in a typical design course, there are two major activities in our course model: lectures and student projects. The purpose of the lectures is not to teach the students profound theories, but to help the students build their own “design tool box” -- to let them know what tools are available to them to design, and to give proper balance between theory and practice.

A variety of subjects are taught in this one-year course, and each subject is taught for only about two weeks. With the purpose of building a design tool box, the lectures really emphasize breadth rather than depth, applications rather than deep theories. The agenda on one of the subjects, “Computer Aided Design – Finite Element Analysis,” is attached in the Appendix for reference. It is expected that after the lectures, students possess a basic understanding of the subject, and are able to further study the subject on their own when they
need to use the design tool, or to take an advanced course on the subject if they find themselves interested in it.

It is always interesting to identify the subjects that should be taught in a “design” course. It is even more difficult to decide what subjects to teach when our design course is not integrated into any specific curriculum, i.e., not related to any specific knowledge domain. Currently 12 subjects are arranged in our course model. These subjects were selected because we think they are the fundamental tools that the students must have in order to be able to perform mechanical design.

2. Structural Analysis.
4. Mechanical Components (I) -- Transmission.
7. Sensors and Electronic Components.
8. Design Drawings and Documentation.
9. Mechanical Components (II) -- Bearings, Bolts, Clutch, and Brakes.
11. Mechanical Vibrations.

This is a rather drastic change in content from the more “traditional” mechanical design courses in the universities in Taiwan. There can be no standard textbook. Substantial handouts are prepared. The subjects and the content of the subjects are reviewed and updated each summer to reflect the latest changes in technologies and local industries.

Each subject in itself can be a one-semester course. Some people may question whether it is a good strategy to rush through a subject in two weeks, for a total of about six hours of lectures. Students may have learned some of the subjects in their previous courses, or they will take a course in one of the subjects. On the other hand, some students will never have a chance to take a course on certain subjects during their four years in college. After the course, the students may not become experts in any of the subjects, but for many students on certain subjects, these six hours may be the only time that some of the design tools are displayed to them.

A quiz follows each subject immediately. There is only one problem in the quiz, and it is identical to one of the example problems discussed in the lectures, or one of the exercise problems in the students' homework. The main purpose of the quizzes is to make sure that the
students still pay enough attention to the theoretical aspect of the lectures. This type of quiz also relieves the TA's working load of grading more than one hundred homework sets.

IV. Small process-oriented design projects

I also believe that student design projects are an essential and necessary part of a mechanical design course. Before installing student design projects into the design courses, one important question to ask is, what does the professor want to achieve with the design projects?

The answer to this question may vary from course to course, from professor to professor. For the course model and myself, there are several answers that are not what I want to achieve with the student design projects. The purpose of the design projects is not to ask students to invent something new that they can patent. The purpose of the design projects is not to help the students sharpen their skills on the drawing board or in the manufacturing workshop. The purpose of the design projects is not even to build a real usable product.

The purpose of the student design projects in my course model is to let the students experience design, so that they can learn things that they do not learn in the lectures, textbooks, and homework sets. The student projects are intended to be a design problem to be solved, rather than a product to be built.

With this pedagogical goal, the design projects in this course model are small process-oriented projects rather than large product-oriented projects. After each subject is taught, students form teams of three or four to do small-scale design projects. In a design project, students are expected to use the design tool just introduced in lectures, to experience the design process and to demonstrate their ideas and creativity.

In this format, resource limitation does not seem to be an important problem. Inexpensive materials such as straws, foam core, Lego’s, basic electronic components, small motors and public domain software are given to the students for their projects. Students are encouraged to use whatever is available to them to solve their design problems, just as a real engineer would do, instead of relying on having expensive, high precision equipment. In a project, students usually have to design simple experiments using coins, rubber bands and chopsticks to measure various data or system parameters required for their design. The projects are also carefully designed so that most students themselves have the necessary “equipment,” such as bicycles, motorcycles and personal computers, to finish the projects. Many students finish most of their design projects in their dormitory rooms. For example, since many students ride motorcycles to school, the project for “Mechanical Vibration” is to model a motorcycle as a mass-spring-damper system. Each design team has to measure or estimate the parameters of the system, to calculate dynamic responses when riding the
motorcycle over a bump on campus road using simple spread sheet program. Finally the students are asked to “redesign” the suspension of the motorcycle for better ride quality.

Another resource problem we have to deal with is that the professor and TA do not have enough time to coach each design team. Therefore an adapted “guided design procedure” [10] is built into the design projects. Guided design is a structured way of having students work through case studies. The guided design procedure advances step by step through a specific problem-solving or design procedure [11]. Wales and Nardi [12] recommend the following ten steps:

1. Outline situation
2. Define goals
3. Gather information
4. Suggest possible solutions
5. Establish constraints
6. Choose solution path
7. Analyze factors needed for solution
8. Synthesize solution
9. Evaluate solution
10. Make recommendations.

In Wales and Nardi’s model, for each step, the students first complete the step then receive and discuss the feedback, a printed sheet of paper which tells what the professional engineers did in this case.

The guided design procedure is adapted to our course model. Instead of case studies, a large term project is divided into several small projects, each relating to a subject of the lectures. For example, the term project this year is to design a Lego race vehicle with various sensors to control its motor and a ping-pong ball it is going to shoot into a goal at the end. This project is divided into seven small projects related to the first seven subjects mentioned in the previous section. Each project is part of a step-by-step system design procedure which is either to develop the specifications, to generate various design concepts for a subsystem of their final design, or to do certain analysis or evaluation for their design. A race (rather than a design contest) was held after the students finished the term project. “Coolness” was strongly emphasized in the race to encourage student creativity.

In this adapted guided design procedure, the professor and TA do not have to supervise each team closely. However, the major feedback the student teams will get are the comments the professor gives to the written reports of each team on each projects. It is crucial that the professor focuses efforts on grading the reports, giving useful comments to the students. In the standard guided design procedure, it is the design process that is being taught, and not a
particular answer. Therefore it is important to stress that the feedback sheet does not represent the solution but only shows what the professionals did. But in our student projects, it is important to assess correct use of the design tools just learned and therefore is included in the professor's feedback.

V. Implementing the design course model

This course model has been implemented in the Mechanical Engineering Department of Yuan Ze University rather successfully for four years now. At the end of each year, a questionnaire was distributed to survey the students acceptance of this model, and identify modifications for the next year. The following statistics are from the questionnaire of 1995–1996 academic year.

On the content and projects of the course, about 70 percent of the students felt the content was adequate, while the projects did seem to be overloaded. 85.6 percent of the students spent five hours to a few days to finish each project. But 46.4 percent of the students liked the projects more than the quizzes, compared with 14.4 percent of the students who liked the quizzes more.

On team cooperation, only 50.5 percent of the students agreed that the project is the effort of all team members. But students seemed to accept that in a team, they have to deal with the fact that some of the members may not do the fair share of the work. All team members get the same grade for the team project, but only 5.2 percent of the students felt the grading system is not fair. Finally, 70.1 percent of the students liked this course model, while 83.5 percent of the students felt this model raises their interests in the course, and 85.6 percent agreed that this model helps them learn the course materials more effectively.

Besides the feedback from the questionnaire, I also have some observations about implementation of the model in the four years. Students' interests in the course seemed to stay at a high level through the two semesters, since they encounter a new subject almost every two weeks. There was not a lecture on “how to be creative,” but in the design projects, students seemed to be rather creative when relieved of the burden of manufacturing, using expensive, high precision equipment and fancy commercial software. Students did not have to put too much effort on the craftsmanship of manufacturing, as in a workshop course. They did not have to devote all their attention to obtaining the most precise data in the experiments, as in a physics lab or an experimental mechanics course. They did not have to follow the instructions step by step to learn to use software, as in a CAD/CAE course, leaving the students significant room for creativity.

One negative effect of this kind of design project is that students tend to be less familiar with the manufacturability issues of mechanical design. Therefore, design for
Manufacturability is an important subject on the agenda of the senior design project course, which I also teach. Students in this course have to build real products. However, it is an optional course in our department and only 30 students can be admitted to the senior design course because of limited resources.

VI. Discussions and conclusions

This paper presents a course model, which attempts to incorporate student design projects into junior-level mechanical design course in a large-class setting. This model appears to be quite successful when implemented in the Department of Mechanical Engineering, Yuan Ze University, Taiwan.

This paper does not intend to discuss the culture issues of the attitude of Chinese professors and students toward design. However, I wish to point out that the size of the class is not the only difficulty of teaching design courses in Taiwan. In the questionnaire to the professors teaching mechanical design courses, one professor stated “In general, the professors do not have enough experience in design practice and system design.” Most professors were trained by the more “traditional” curriculum, which does not emphasize design. And despite almost general agreement on the importance of design practice, it does not connect to the professors’ other mission -- research.

Finally, our universities should acknowledge the importance of design courses, and do an adequate job of financing design courses and rewarding the participation of professors.

VII. Acknowledgement

I would like to thank Mr. Wang, Shin-Gou, my graduate research assistant, for helping me with the administrative work of this research. This research is partially sponsored by the National Science Council, Taiwan, grant number NSC84-2511-S-155-002 and NSC 86-2512-S-155-001-EE. This support is gratefully acknowledged.

References


http://designer.mech.yzu.edu.tw/

**Appendix I: Questionnaire and statistics on the current situation of mechanical design courses in universities in Taiwan**

1. How many mechanical design classes are you teaching right now? The sizes of your classes are

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Class Size</th>
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<tbody>
<tr>
<td>2.0%</td>
<td>Below 30</td>
</tr>
<tr>
<td>13.7%</td>
<td>30 to 39</td>
</tr>
<tr>
<td>45.1%</td>
<td>40 to 49</td>
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<tr>
<td>23.5%</td>
<td>50 to 59</td>
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<tr>
<td>9.8%</td>
<td>60 to 69</td>
</tr>
<tr>
<td>5.9%</td>
<td>Over 70</td>
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</tbody>
</table>

Note: The percentage is based on number of sections.

2. Are there student design projects in the mechanical design course you are teaching?

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>40.0%</td>
<td>Yes</td>
</tr>
<tr>
<td>60.0%</td>
<td>No</td>
</tr>
</tbody>
</table>

Note: The percentage is based on number of total sections.

3. In your opinion, what are the possible difficulties if you arrange design practice projects in the mechanical design course you are teaching?

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Difficulty</th>
</tr>
</thead>
<tbody>
<tr>
<td>66.7%</td>
<td>The size of the class is too big,</td>
</tr>
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</table>

http://designer.mech.yzu.edu.tw/
72.7 percent  lack of budget and proper environment,

24.2 percent  lack of proper textbook,

45.5 percent  professors do not have enough time,

15.2 percent  students do not have enough ability

_____ others.  time is not enough (12.1 percent), manufacturing difficulties (12.1 percent), students are not willing to spend time on design practice (9.1 percent), teachers do not have enough experience (3.0 percent), lack of proper projects(3.0 percent).

4. Do your department have other related courses for mechanical design projects?

35.0 percent  yes, and they are required courses,

35.0 percent  yes, and they are optional courses,

30.0 percent  no.

Note: The percentage is based on number of different mechanical engineering departments.

5. The content of the mechanical design courses includes,

51.5 percent  structural analysis, 93.9 percent  machine component design,

12.1 percent  mechtronic design, 15.2 percent  mechanical vibration,

15.2 percent  hydraulics and pneumatics, 30.3 percent  system design methodology,

12.1 percent  geometric modeling, 18.2 percent  computer aided analysis,

15.2 percent  design optimization,

36.4 percent  design drawings and documentation

_____ others.  linkage design, reliability engineering, fixture design

Note: This questionnaire was originally in Chinese.
Appendix II: Agendas on “Computer Aided Design – Finite Element Analysis”

1. General Introduction
   a. Discuss why and where mechanical designers need to use finite element analysis.
   b. Introduce the process of finite element analysis.

2. Fundamental Theory
   a. Use the 1-D spring element to explain the basic concept of nodes, elements, and boundary conditions.
   b. Explain the concept of the element stiffness matrix, and how the system stiffness matrix is assembled.
   c. Demonstrate how the system equation is solved.
   d. Discuss the conceptual extension to general structural analysis.

3. Computer Application
   a. Discuss how to plan for building a finite element model using a computer program.
   b. Use examples to describe the possible mistakes when building a finite element model.

4. Design Application
   a. Demonstrate the finite element analysis for a simple structure.
   b. Discuss how to use the results from finite element analysis to redesign the structure.