Teaching Capstone Design in Globalization Environment

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Abstract

In an effort to improve the mutual understanding and communication among future engineers in a globalization environment, the authors have started to establish a set of common course material and design tools for capstone design education. Internationalized course material will be web-accessible with permission. The course material with design tools, such as a design case library and optimization programs, will be jointly developed and used by faculty members and students around the Pacific Rim. Although a capstone design course is usually required in an engineering curriculum, the format and content can be very different at different engineering schools. The paper discusses the effort to find common ground in different educational systems. The paper also addresses the perceived subtle difference resulting from cultural preference in teaching and learning engineering design. Some considerations for a change of methodology in teaching and doing mechanical design are proposed. Benefit and possible solutions to potential problems are presented as well.

Introduction

Rapid advances in computer and communication technology have provided the opportunity for developing new, more powerful and efficient tools for conducting business, which includes in particular the field of engineering education and mechanical design. Driven to take advantage of the available technology and started in 2000, the authors collaborated in an effort to compare the differences and similarity in teaching capstone design in mechanical engineering curricula in a few universities around the Pacific Rim. The purpose was to determine if a common set of teaching materials and tools can be shared by faculty members in different countries. The benefit for the students in using common learning materials and design tools is that they would be better prepared to work in a global environment, either to collaborate with engineers in different countries, or to work in a foreign country.

The capstone design course was the first among the topics for discussion. Although a capstone design course is always required in an engineering undergraduate curriculum, the format of teaching this course can be very different. According to a recent survey [Manring, 2003] for capstone courses taught in mechanical engineering, the duration varies from one semester to two semesters, or up to three quarters. Some schools require the completion of a working prototype of the design by the students, and some do not. Unlike the textbook in mechanisms or machine components, current choices for textbooks of mechanical engineering capstone design courses are also wide and large. These differences exist among engineering schools not only in the US but also in other countries [Hsu, 2003]. If the capstone design course is more different than other courses, such as Statics and the Fundamentals of Thermodynamics, then why are we trying to assimilate and build common ground in this course? Why should we put the effort in internationalizing this course in particular? In ABET requirements and most engineering curricula, the students are required to apply and demonstrate knowledge obtained from other undergraduate courses in the capstone design course. The capstone course is a summary and reflection of the whole undergraduate curriculum. Therefore, internationalizing this course has special significance. The effort on this course will serve as the basis for discussion and exploration for internationalizing other courses. In addition, it is reasonable to assume that engineering schools in different countries have some common requirements and expectations for graduating mechanical engineers, and some common practice to achieve these requirements. There are some common practices in this course, including centering of the course around a capstone design project, organization of the students into design teams, and the requirement for team presentation and defense of their design at the end of the semester.

One significant difference in capstone design courses is the inclusion or exclusion of a formal lecture. Some engineering schools believe there should not be any formal lectures in this course. The instructor serves as a coach and manager of the design projects. Some other schools may consider that a one-hour weekly lecture may be necessary to provide students with basic system design concepts that are not covered in the machine component design course, and a thread to bind course materials and tools from other undergraduate courses. The proposed plan was to develop core material consisting of 12-units of lecture notes. Even for this minimum intersection set of many different sets of interests and requirements, it can be tailored by adding or subtracting special needs. With this set of lectures, some common design tools will be identified or developed. These design tools could be located at a single web site, but could also be located conveniently in different engineering schools in different countries.

This paper first explains the rationale for choosing course materials as basic and common sets. Then the web-accessible mechanical design tools developed are briefly described. Differences in cultural and educational systems and their effects in teaching and learning are also discussed. Finally, ideas for preparing a profound change in the methodology of teaching and practicing mechanical design are suggested in the conclusion.

Developing Shared Teaching Materials

In our effort to develop a common set of teaching materials for capstone design in mechanical engineering, the following factors were considered as important:
1. Some materials that have been used by at least one of the participating schools, and proven to be effective;
2. Approaches to mechanical design which are quite different in different countries were pointed out and a preference was suggested;
3. New materials that the authors consider valuable to put into the base set.
Based on these considerations, the plan was to include the following basic units developed in a Capstone Design Manual.

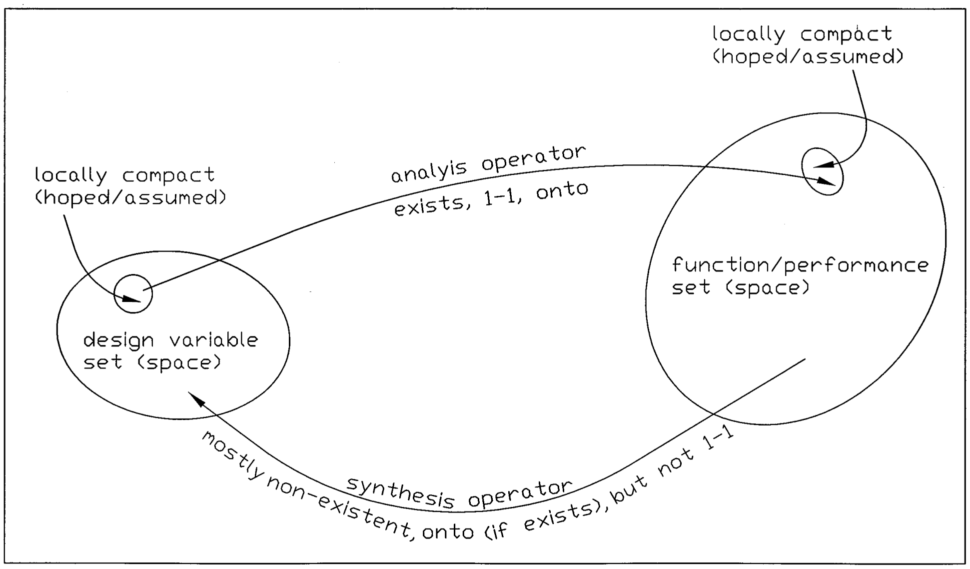


Fig.1 Conceptual difference between analysis and synthesis type of courses

1. Introduction The capstone design is a synthesis type course, and most engineering courses are analysis type courses. The difference between these two types is illustrated in Fig.1. If a design is specified by a set of design variables, then the performance of the design can be analyzed using knowledge from different engineering courses and by using available computer software. However, all design tasks are specified by the end function, the performance. A synthesis operator that will map uniquely to a set of design variables from functional requirements does not exist. In fact, rigid and non-negotiable design requirements may not have a design solution. Traditionally and currently, most designs are still accomplished using a trial-and-error process. This is why students deserve to get an early warning that this course is different, and some may feel the course is not well structured, since there is no strict logic relationship between proceeding and following chapters as in an analytical course. In contrast to art and literature students, engineering students may not be used to the idea of a vaguely defined problem, and open-ended solutions to a design problem. In general a design problem is usually not well defined. Students will need to know that they have to think differently in this course.

2. Team organization and dynamics This topic is related to project management, and is one that is gaining importance in the US and not yet emphasized in Asian countries. Due to the complexity of modern design, the development of a new machine or product is becoming more and more a collaborative social activity. While students need to contribute to a team project individually, it is important to learn to cooperate with the team. Some engineering schools in the US have used

personality and temperament tests to organize the most productive design teams. Our assessment is that learning to work with different personality types in a team, at the minimum, will help students learn to work with others in a more productive way.

3. <u>Developing detailed design specifications using the Quality Function Development(QFD) method</u> Ullman [2003] popularized the QFD method in US engineering schools in his well adopted book *The Mechanical Design Process*. This method is important for turning vague, not measurable customer needs for a new design into a set of measurable engineering specifications. Although this method was proposed in Japan in the mid-70's, it is still not well known or popular in Asian engineering schools. Experienced design engineers can design well without explicitly using this method, however, it is very helpful to learn this concept in teaching and learning the design process. Figure 2 is a very good example of how well prepared QFD can help in a SAE Formula car turbo charger design. Starting from the top left, each row addresses a customer concern. In the columns to the right, performances of competitions (or state of the art) were ranked. Then reading from left to right in the middle columns, measurable design targets addressing the customer concerns are clearly listed in the bottom row.

4. <u>Basic methods and tools for project planning</u> Because capstone design is a team project and not a personal effort, setting up a commonly agreed upon schedule for the team is very important for the success of the team. Critical Path Method (CPM) and the software tool, *MS Project*, can be quickly taught and applied. A non-traditional use of the planning is to have a cost estimate with the planned man power and delivery time [Ulrich, 2000].

	Amateur Auto-cross Racer	SAE Competition Judges	Manufacturing Personel	MU Team	Mechanic	Marketing	Reliability (%)	Horsepower (h.p.)	Torque (ft. lb.)	Customers finding it visually appealing (%)	Customers finding it audibly appealing (%)	Manufacturing Price ($)	Weight (lb)	Manufacturing Processes Required (#)	Time to Manufacture (hrs.)	Noise Level (db)	Time to install (hrs.)	Time to disassemble (hrs.)	Average repair cost ($)	MU car #54	MU car #4	UTA car #99
Reliability	4	7	7	2	2	6	9													4	1	1
Performance	2	2	8	3	7	1		9	9				3							2	2	4
Looks	5	3	9	10	9	3				9							1			3	4	4
Sounds Good	6	11	11	11	10	4					9									3	4	3
Cost	3	6	5	7	3	2						9		1	3		3		1	4	2	1
Weight	7	4	6	4	8	5							9							4	3	4
Manufacturability	11	8	1	8	11	11						1	1	3	9		1			4	3	3
Ease of Instalation	10	10	2	9	4	10											9	1		4	2	3
With-in Regulations	1	1	4	1	6	7										9				5	5	5
Repairability	8	9	10	5	1	9								1	1		3	3	9	3	3	2
Compatibility with Car	9	5	3	6	5	8				3							3	1	1	2	3	3
MU car #54							90	64	25	60	50	600	5	5	8	125	1	0.5	100			
MU car #4							25	56	22	85	80	2600	23	9	20	118	5	2	500			
UTA car #99							70	80	30	80	90	3000	12	6	20	120	3	2	1500			
Target							95	80	35	85	90	800	6	5	12	110	2	1	100			

Fig.2 A sample QFD chart for SAE formula car design

5. Application of internationally accepted standards in metrology, materials, etc Engineering schools in the US have better computer networks. They can access various databases, such as material property and standards (e.g., ASTM), patents (www.uspto.gov) easily. However, most capstone design textbooks have not paid sufficient attention to the application of these national and international standards. Quality, and very often the functionality, of a design depend on these standards.

6. Preparing detailed engineering drawings From our observation, engineering students in Asian countries receive more basic training in this area. In the states, engineering and technical training are separated and engineering students may not have sufficient training in this subject. This is an area the US engineering students can learn from their counter parts.

7. Review and application of analytical tools, such as FEA software tools Students usually learn how to use commercial software quickly. It is more important for the instructor to help students understand the underlining principles. Design cases demonstrating the correct and incorrect use of powerful analytical software are very helpful.

8. Overview of design optimization algorithms and web based tools It is not difficult to understand the idea of optimizing a design. The more difficult part in using optimization techniques in undergraduate capstone design is the formulation of the design problem into a mathematical model so that computer tools can be applied. An Internet-based, web-accessible optimization algorithm library has been developed [Huang, 2000; Lee, 2001]. These tools have eliminated the need for individual students or engineers to always keep optimization software on their personal computers.

9. Function decomposition, and other methods for generating design concepts Adams [1986] offers a good overview of general design creativity and covers methods for creating. However, creativity in specific mechanical design topics can be quite different from general creativity. Instructors and students need to have a good understanding of the difference. A major difference is that more experience usually helps in producing a better and creative solution.

10. Writing project proposal, progress report, and final project report In a democratic system, the leader of a design project team has the duty to solicit support and justify the need to carry out the project. Preparing a convincing design proposal is an important part of a design project. It is also very important that the design team summarize the progress and reports to colleagues, supervisors, and the client. A refresher in technical writing [Gerson, 2000] is helpful.

Other units of material that we have included in the initial base set course material are as follows:
11. Cost estimate at different level and stage.
12. Ethics, product liability related to design practice.

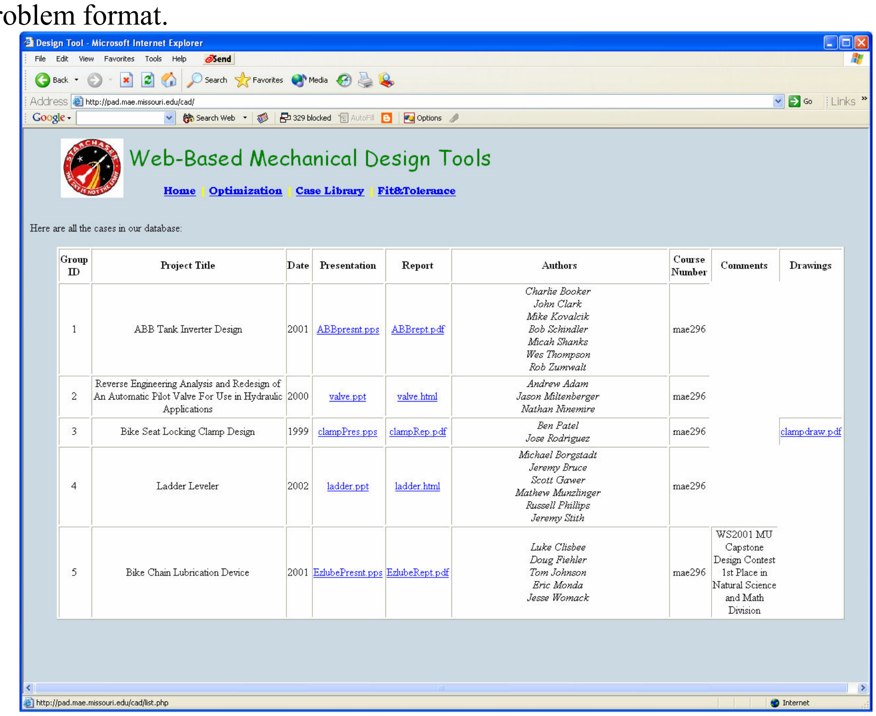
Developing Shared Design and Teaching Tools

To use the base set of lecture materials and Capstone Design Manual, some web-based tools have been developed. Others recognized as useful will be developed in the near future. The developed teaching and design tools include a design case library, a tolerance/fits specification tool, an optimization subroutine library, a cam-follower modeling and dynamic simulation tool, and a tolerance stack analysis tool. A more general purpose mechanism simulation program is currently being implemented. These tools are useful not only in learning and teaching capstone design, but also in professional mechanical designs. The following are descriptions and uses for some of these tools.

The design case library It is accepted that an engineer can gain design experience by carefully studying the design cases [Ullman, 2003] of others. To make learning from existing design an efficient and interesting process, selected design projects have been stored in a relational database (mySQL on Linux platform) with design report, presentation slides, and detailed CAD drawings. Instructors can add comments to these design cases, explaining why and what practice is recommended, and if there was any problem in the prototyping process. Thought provoking questions were inserted to help the reader participate actively in the learning process while reading these design cases. The design case library is searchable using a web browser by key words or project completion time. A front page of this design case library is shown in Fig.3.

A tool for tolerance and fit specifications As educators for capstone design courses, we have seen more prototypes fail to function as intended due to improper design specification of details, rather than a bad basic idea. To help students prepare professional quality specifications, a tolerance and fit specification tool has been developed. Fig.4 shows the entry screen of this tool. Other tools, such as the tolerance stack analysis tool, will be added in the near future. To use these tools effectively, plenty of examples are provided online and lecture notes on these subjects are also available.

Optimization subroutine library Senior students taking capstone design may not have taken a course in optimization theory. However, it is possible to teach students the basic ideas and concepts of design optimization. With convenient access to optimization subroutines or software, and a computation facility, optimizing every design problem becomes a possibility. Currently, the developed optimization library contains only two algorithms. One is the simplex algorithm for linear programming and the other is an implementation of a genetic algorithm for nonlinear problems. The front page of this optimization tool is shown in Fig.5. The user has to prepare the objective functions and constraints in commonly accepted optimization problem format.



Group ID	Project Title	Date	Presentation	Report	Authors	Course Number	Comments	Drawings
1	ABB Tank Inverter Design	2001	ABBpresnt.pps	ABBrept.pdf	Charlie Booker John Clark Mike Kovalcik Bob Schindler Micah Shanks Wes Thompson Rob Zumwalt	mae296		
2	Reverse Engineering Analysis and Redesign of An Automatic Pilot Valve For Use in Hydraulic Applications	2000	valve.ppt	valve.html	Andrew Adam Jason Miltenberger Nathan Ninemire	mae296		
3	Bike Seat Locking Clamp Design	1999	clampPres.pps	clampRep.pdf	Ben Patel Jose Rodriguez	mae296		clampdraw.pdf
4	Ladder Leveler	2002	ladder.ppt	ladder.html	Michael Borgstadt Jeremy Bruce Scott Gawer Mathew Munzlinger Russell Phillips Jeremy Stith	mae296		
5	Bike Chain Lubrication Device	2001	EzlubePresnt.pps	EzlubeRept.pdf	Luke Clisbee Doug Fiehler Tom Johnson Eric Monda Jesse Womack	mae296	WS2001 MU Capstone Design Contest 1st Place in Natural Science and Math Division	

Fig.3 A list of searched design cases

Working with Differences

In the process of internationalizing the capstone design course, the authors observed some subtle cultural differences in the teaching and learning processes. Because this affects the way capstone design can be taught, it is worthwhile to have a more detailed discussion here.

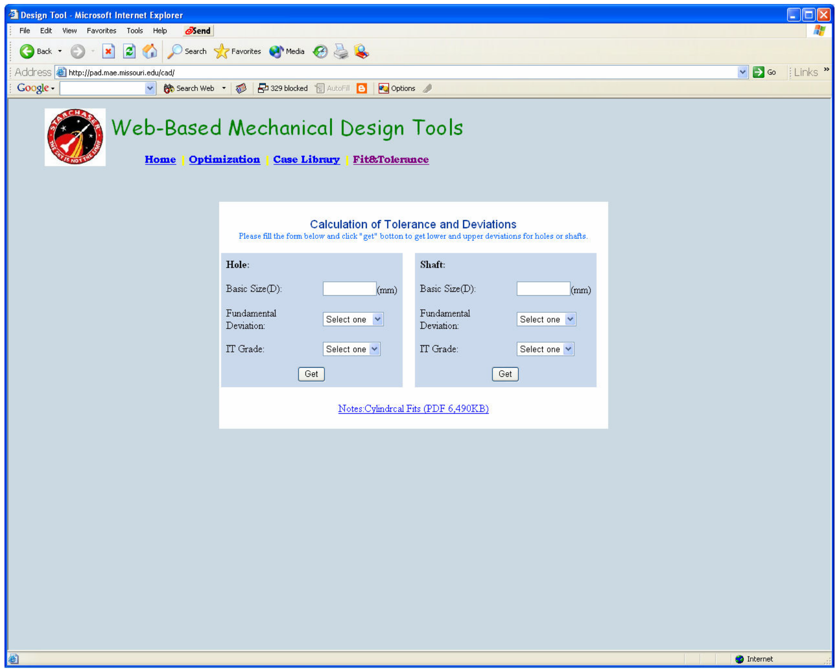


Fig.4 Front page of cylindrical-fit specification tool

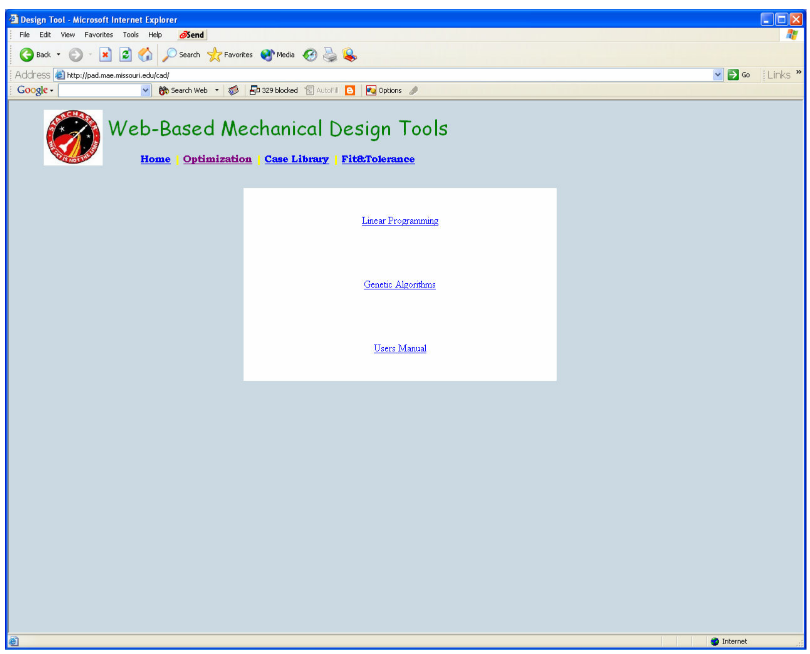


Fig.5 Front page of design optimization tool

One difference is that teaching mechanical design as a process is more popular in US, as illustrated by the two influential capstone design textbooks [Ullman, 2003; Dieter, 2000]. However, teaching a mechanical system design starting with functions of components, then integrating components into a new system is more popular in Asian schools. It is also popular in some US engineering schools to teach creativity in design. The Adams books [1986a, 1986b] have been used by some well known schools for this purpose. However, in some Asian engineering schools, studying the anatomy of well known mechanical system is a must. These differences are examples of using an inductive or a deductive process to teach and to learn.

Our suggestion is to point out such fundamental but subtle differences in the courses, and take advantage of these different ways of thinking in approaching a design project. For some projects and at some certain stages of the design, taking a particular approach may be more effective. Understanding the advantage of taking a top-down or ground up approach to a design project can be very helpful in learning and in practical design work.

Another difference is the emphasis in types of design topics. Should we encourage new ideas and break through concepts in design project topics, or choose those that require attention to detail backed by traditional wisdom? An example of this difference is that in a typical semester in a US engineering program students teams may be designing ultra light airplane, surgical tools and musical instruments, and in an oriental engineering program student teams may be working in the processing equipment design for a specific product, including jigs and fixtures, specialized cutting tools (which can be as specialized and detailed as gear hob and broaching cutters), manufacturing process and automation of the processing equipment.

Our suggestion is that these different emphases and approaches really have a lot to learn from each other. Highly specialized training may reduce employer based training if the graduating engineer landed on a job in the area where he/she is well trained. Broadly trained graduates will be more adaptable to different challenges, while require longer time on-job training provided by the employer. An important work for the instructor is to introduce to the students these different approaches in engineering design education. Hopefully the students can appreciate the strength in these different approaches, and take a more or less compromised approach of their own.

Conclusions

Whether we like it or not, we live in a globalized environment. Cooperation and competition are both presenting themselves on the world stage. Engineering faculty members in different countries can help engineering students to be better prepared for the globalized environment by internationalizing the curricula. Capstone design course is suitable to be internationalized, because it is offered by all engineering programs around the world. Internationalized capstone design course can be used to calibrate other courses in different engineering curricula. This paper presented a plan and suggestions to internationalize the capstone design course in mechanical engineering. Substantial effort has been in the development of teaching materials and design tools. With more teaching, learning, and developments of web-based mechanical design tools, we as engineering design educators need to consider more profound changes in design and education methodology. There is no doubt that more engineering course materials and associated teaching and learning tools can be online and easily accessible from anywhere in the world. Change in the tools we use to teach and practice design will affect the way we teach, learn, and practice mechanical design. Lifelong learning with computer and Internet tools will become easier and necessary in the global market. Instead of passively adopting changes, engineering faculty members should embrace and lead the technological revolution in the globalized environment.

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