A project-based approach to the teaching of Computer Aided Engineering to a multidisciplinary student population

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ABSTRACT: In this article, the authors chronicle experiences in teaching a graduate course on Computer Aided Engineering (CAE) to a very diverse student sample. An aspect of the diversity was the undergraduate degrees that the students had, which included: mechanical engineering, electronics engineering technology, industrial technology, chemical engineering, business administration and psychology. These degrees were earned the USA, China and Japan. The age group was from 26 to 48. Their industrial experience varied from zero to 20 years. Most students had little background in mechanics of materials and design. The challenge that this rich diversity presented also afforded a good learning experience. The topics covered included: 3D modelling using *Pro/ENGINEER*, finite element analysis using *ANSYS*, and rapid prototyping using the Helisys 1015 machine. The pedagogical approach adopted was to use a term-long project as a vehicle for applying CAE knowledge in contrast to focusing on theoretical concepts. A multidisciplinary team-based approach was used for the project completion. The motivation behind the project was to provide students with an overall idea of the product development cycle starting from the conceptual idea to manufacturing a prototype.

INTRODUCTION

The course TECH 5311 *Computer Aided Engineering* was offered as a graduate-level elective for technology major students. No specific prerequisite courses were assigned. Traditionally, graduate students in technology have bachelor's degrees in industrial technology and engineering technology. With the consent of the instructor, the course is also available for other majors. Other majors take this course because many students work in the high-technology dominated industries in the central Texas region in the USA. Consequently, the non-technology/engineering employee also has to deal with issues from the realm of computer aided engineering; at least in a tangential manner, as they interact with their technical counterparts in a multidisciplinary team-oriented workplace.

This semester, six students who had undergraduate degrees in mechanical engineering (ME), electronics engineering technology (EET), industrial technology (IT), chemical engineering (ChE), business administration (BA) and psychology enrolled. The diverse background of students provided the impetus to tailor the course so as to dissipate the direct and applied knowledge related to the product development process from a *Computer Aided Engineering* point of view.

The approach detailed in this article was to simplify the theoretical and mathematical portion and to use the commercial software like *Pro/ENGINEER* and *ANSYS* to solve real life problems on product design. The topics selected for the lecture portion of this course revolved around the project. The broad topics were decided as follows:

- Fundamental concepts in design;
- 3D Modelling using *Pro/ENGINEER wildfire* 2.0;
- Finite Element Analysis (FEA) using *ANSYS* 10.0;
- Rapid Prototyping (RP) using Helisys 1015.

It was realised that in order, to teach the abovementioned topics to the diverse audience, a term-long project would be a great learning experience as it afforded opportunities for multiple applications. The product selected was *banana hanger* considering its simplicity (since practically everyone is familiar with this household product) regarding designing, modelling, analysing and prototyping. Two teams were formed based on students' background. The teams exhibited a good mix of different attributes as displayed in Table 1.

Table 1: Attributes of the two design teams.

Attribute	Team A	Team B
Undergraduate degrees	ME; Psychology BA	ChE; EET, IT
Country of graduation	China, USA, USA	Japan, USA, USA
Occupation	2 FT student 1 FT job	2 FT student 1 FT job
CAD/CAE knowledge	MDT, MDT, MDT	N/A, AutoCAD, MDT
Gender	All males	1 female, 2 males
Age	28 to 32	26 to 48

MDT: Mechanical Desktop; FT: full-time

TEACHING SCHEDULE

This course was taught once a week for about three hours. The total class duration was divided into two parts. Two hours were devoted to instruction in fundamental concepts related to engineering materials, strength of materials, and design of machine elements, Finite Element Analysis (FEA), and rapid prototyping. One hour was reserved for learning *Pro/ENGINEER wildfire* 2.0 and *ANSYS* version 10.0. Typically, students spent one-hour in-class and two hours out-of-class time on learning *Pro/ENGINEER* and *ANSYS* software. It was observed that the learning curve for both these

software were pretty steep. The assigned textbook for *Pro/ENGINEER* systematically explained the process of geometric modelling by the medium of click-by-click tutorials [1]. *ANSYS* tutorials were chosen from University of Alberta Web site [2]. The class instruction was correlated to the different stages in product development process. The following section explains the different stages in teaching and product development activities.

TEACHING AND PRODUCT DEVELOPMENT

Stage I [1 Week]

Teaching Activities

Different terms related to Computer Aided Engineering (CAE) were explained. These were CAD, CAM, CAE, rapid prototyping; common file formats (such as *.iges and *.stl), and important stages in design and the product development process. The important stages explained were conceive, design, develop, manufacture and validate as shown in Figure 1 [3]. The role of CAE in the context of 3D modelling and FEA was clearly explained (see Figure 2). Sample analysis and simulations were showed to explain the current applications and importance of CAE [2][4]. Dynamic simulations using LS-DYNA attracted student's attention.
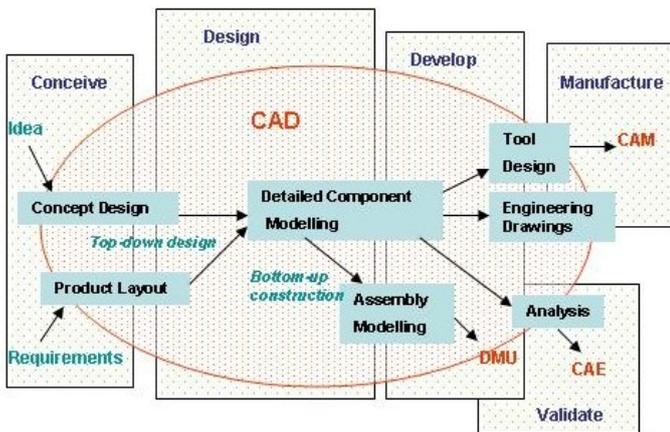

Figure 1: Product development: the role of CAD and CAE [3].
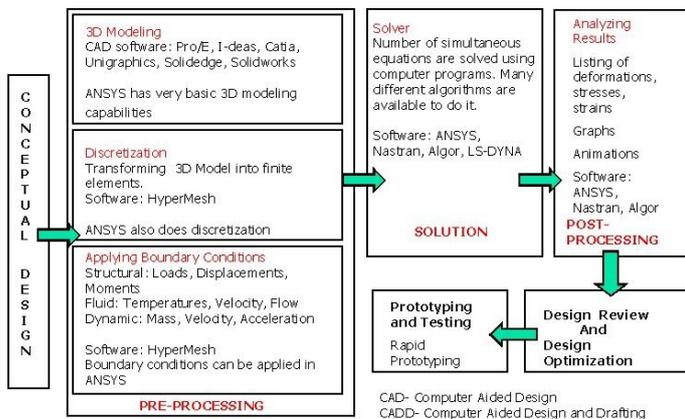
Figure 2: CAE with reference to commercial software.

Product Development Activities

Students were required to collect background information about the banana hanger. This information included: product need, available products on market, material of construction, manufacturing processes, price, aesthetics, utility value,

number of bananas to be hanged and the shape-size-weight of bananas.

Stage II [3 Weeks]

Teaching Activities

The next topics related to *engineering materials* were taught in the class. The sub-topics included the following:

- Engineering materials: properties, applications and selection;
- Ductile and brittle materials: difference, examples, fracture;
- Concept of specific strength and specific stiffness in the context of aluminium and composite materials;
- Safety factor: selection, fail safe and safe life approaches;
- Stress-strain curves for ductile, brittle materials, plastics and elastomers [5][6].

Students were also exposed to non-traditional materials such as plastics and composites.

Product Development Activities

With the background knowledge about materials, students were asked to select the materials, safety factor and manufacturing process for the banana hanger. Each team documented the proper reasoning for material and manufacturing process. It was observed that students preferred metals rather than plastics. This is because they did not have sufficient knowledge about plastics and composites. The need for courses in these materials in the current curriculum was strongly felt. Students were encouraged to locate the values of strength, Poisson's ratio and other mechanical properties using open literature available on the Internet such as *Matweb* [7].

Stage III [3 Weeks]

Teaching Activities

The teaching activities were continued as mentioned in stage II and stage IV.

Product Development Activities

This was the innovative step and students were asked to brainstorm and output as many ideas as possible through rough sketches. They were encouraged to think laterally. In the next step, students finalised one idea considering simplicity, utility, aesthetics and price. They were asked to decide the curves and height of the banana hanger with proper reasoning and document uniqueness of their design compared to ones available on market. In the next step students were asked to present their design using 3D models prepared using any software. Both teams preferred using *AutoCAD*.

Stage IV [3 Weeks]

Teaching Activities

Next, fundamental topics related to the strength of materials and the design of machine elements was taught. These topics include stress, strain, axial and strain, Poisson's ratio, modulus of elasticity and rigidity, types of stresses-tensile compressive shear, bending of beams, torsion of shafts, column buckling, safety factor – fail safe and safe life approach, selection,

concept of optimum design to utilise material to its fullest capacity, stress concentration factor, principal stresses in 2D, theories of failure for brittle and ductile materials. The derivations in the above topics were omitted and only an applied treatment was emphasised. A few sample problems were demonstrated in each category [6][8].

Product Development Activities

After teaching these topics, students were able to recognise the types of stresses experienced by a specific part. To clarify their ideas, different examples, such as a fishing rod, airplane cabin and chair, were explained. The combined direct and bending stresses example was elaborated in detail so that students could use it in their banana hanger design project. At this stage, students were asked to provide their hand calculations. They simplified the curved design in such a way so that they could perform calculations.

Stage V [3 Weeks]

Teaching Activities

At this stage, the importance of Finite Element Analysis (FEA) was explained. The complex nature of stresses in a banana hanger was highlighted and difficulties in hand calculations were demonstrated. The topics covered in FEA were definition, steps in FEA – pre-processor, solution and post-processor, different software available on market for the different steps in FEA (such as *Pro/ENGINEER*, *HyperMesh*, *ANSYS*) 1D-2D-3D elements (such as link, quadrilateral, triangular, hexahedral or brick, tetrahedron), the concept of degrees of freedom, analysis time for complex problems, boundary conditions, different solvers available in *ANSYS*, and different files created by *ANSYS* such as *.db and *.log; and importing *.iges and *.prt files from *Pro/ENGINEER* [2][9][10]. Five tutorials were selected from the University of Alberta Web site and were modified for *ANSYS* version 10.0. These tutorials were on a two-dimensional truss, bicycle space frame, plane stress bracket, solid modelling and buckling [2]. The main purpose of these tutorials was to familiarise the FE process and different methods to present the results viz. listing, plotting and animation.

It is worth mentioning the homework activity for the FE analysis. The homework problem required the computation of stress concentration factors for standard geometry using *ANSYS* and comparing the same with values obtainable from standard graphs by Peterson [6]. The homework problem involved modelling and applying boundary conditions repetitively. There were two students interested in using (*ANSYS* Parametric Design Language (APDL). They were encouraged to see the *.log file every time they used any command using GUI. This was the direct approach to teaching APDL rather than teaching command by command. Students soon realised the equivalent *ANSYS* commands to be used at the command line. Both the students prepared the APDL program and used the same in solving this tutorial. They took only a quarter of the time than their counterparts who used GUI. The productivity in design process was explained with this example.

Product Development Activities

This time, students were required to develop the 3D model of the banana hanger using *Pro/ENGINEER*. The advantage of *Pro/ENGINEER*'s feature-based, parametric and associative nature was emphasised. This 3D model was saved in three different formats: *.prt, which is Pro/E's part drawing format, *.iges (Initial Graphics Exchange Specification), which is a common data format used for the transfer of CAD data, and *.stl, which is the common format used on RP machines. The *.prt models were imported into the *ANSYS* environment.

Stage VI [1 Week]

Teaching Activities

The concept and applications of rapid prototyping to the product design and development processes were covered. The different manufacturing techniques, such as fused deposition modelling-FDM (Stratasys, Inc.), sterolithography, selective laser sintering and laminated object manufacturing-LOM (Helsisys, Inc.), were discussed briefly. The Department of Engineering and Technology has Stratasys and Helsisys machines. A detailed demonstration was performed on these machines and different products manufactured on these machines were showcased.

Students were instructed on how to create .stl versions of their designs from the .prt version of the same. The pros and cons of increasing/decreasing the facet density of the stl files were presented. At this stage, students were explained the historical background of STL and IGES file formats. STL is the native file format of the SLA (slective laser sintering) CAD software created by 3D Systems of Valencia, USA [3]. The Initial Graphics Exchange Specification (IGES) defines a neutral data format that allows the digital exchange of information among CAD systems. The IGES project was started in 1979 by a group of CAD users and vendors, including Boeing, GE, Computervision and Applicon, with the support of the National Bureau of Standards [3]. Students were encouraged to visit the Web sites of RP machine manufacturers including 3D Systems, Stratasys and Helisys.

Product Development Activities

At this point, students were taken to the RP facility and some of their stl files were uploaded into the FDM machine. They were walked through the procedures for homing and calibrating the machines. Next, they were guided through the process of setting the build parameters on the machines. The *.stl file was used on the RP machine (the Stratasys) to produce the product using ABS as the construction of the material. Upon completion of the builds, the process of finishing a prototype was demonstrated.

Each team was asked to prepare *PowerPoint* presentation containing the following information: product need, available designs on the market and their pros and cons, the final design as a 3D model, reasoning for selection of particular shape and dimensions, reasoning for selecting the particular material of construction, method of mass manufacturing, design calculations, *ANSYS* outputs for deformation and von-Mises stresses, and conclusions. Each team was also asked to write a detailed project report including the points mentioned in the presentation. Each team was allocated 15 minutes for their presentation and five minutes were reserved for questions and answers. One of the colleagues was invited as an external examiner. The performance was evaluated on the basis of the students' basic understanding of design and analysis, presentation skills, and technical skills. This activity of writing report and presentation improved students' communication skills.

PRODUCT HIGHLIGHTS

Team A

Team A systematically evaluated the pros and cons of banana hangers available on the market. They felt the necessity of foldable banana hanger to save countertop space and its multi-functionality to store other fruits in the bowl (Figure 3). The product consisted of three parts that required assembly. The material finalised for construction was aluminium using pressure die-casting. The design was bulky and underutilised the material. This point was elaborated to students by explaining the values of von-Mises stresses and the deflection of the banana hanger at the point of application of the load.
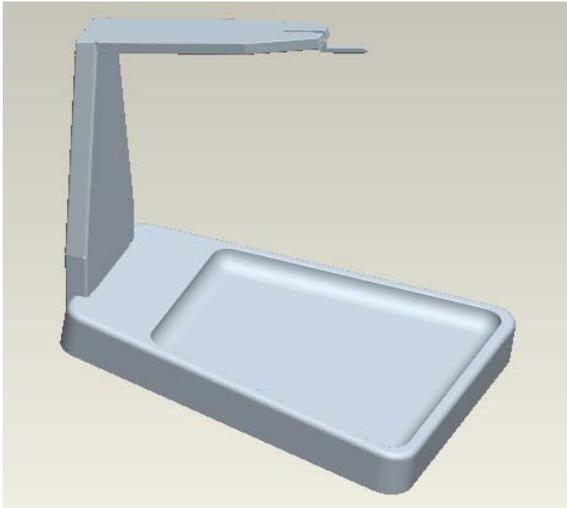
Figure 3: Team A's *better banana hanger*.

Team B

Team B's idea was traditional, but the selected shape and curves were sleek (Figure 4). The product was one piece, which would cut down the cost of manufacturing. This team also utilised the material of construction as aluminium using pressure die-casting. The industrial technology student in this team not only provided the detail reasoning of selecting aluminium die casting as the manufacturing process, but also provided sketches for dies. He insisted on one-piece construction, which would cut down manufacturing costs. The material was utilised to its fullest capacity, which was emphasised by von-Mises stresses.

Both of the teams provided hand calculations for their design considering direct and bending stresses and buckling of vertical column, modelled the product using *Pro/ENGINEER*, imported *Pro/ENGINEER*'s *.prt file in *ANSYS*, performed the analysis in *ANSYS*, and produced RP model on the Stratasys machine using ABS as material of construction.

OBSERVATIONS

- Asian students showed more interest in analysis, namely design, stress analysis and FEA, while American students were more interested in the creative and commercial aspects, such as putting forth new ideas and getting the same patented;
- The psychology student in Team A strongly led the team to push his idea of a foldable banana hanger. Team B's design was sleek and *feminine* in nature The Japanese

female student was instrumental in deciding the curve and shape of Team B's design.
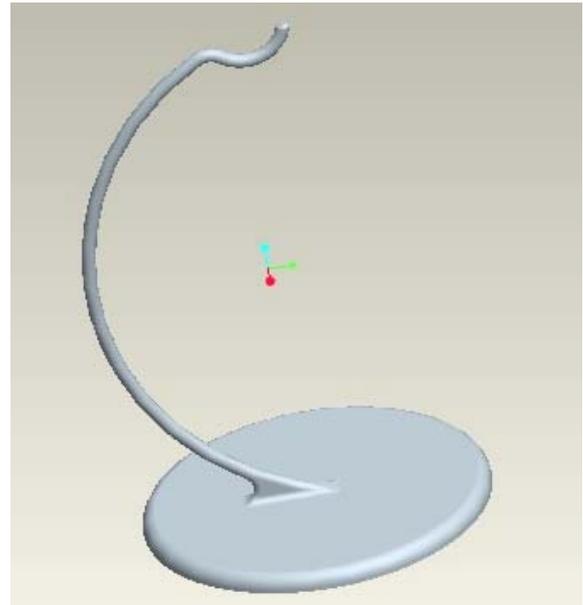
Figure 4: Team B's *banana peg*.

CONCLUSIONS

- Fundamental topics related to engineering materials, strength of materials, design of machine elements, 3D modelling, FEA and rapid prototyping were effectively conveyed to technology students through a simple semester-long project;
- The direct and applied approach, rather than derivations and complex formulae, is more useful for technology and majors from the College of Science and Business whose background in engineering analysis is minimal. Thus, all majors acquired a good feel for the area of CAE;
- With this introductory course, students could work as an efficient team member in a product development team;
- It was observed that students preferred metals rather than plastics. This is because they did not have sufficient knowledge about plastics and composites. The need for such courses was strongly felt.

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