Web-Based Computer-Aided Engineering Tutorials Across the Mechanical Engineering Curriculum

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Introduction

A skill in demand for graduating engineering students is the ability to combine computational tools, intuition, and fundamentals effectively. Those factors are arguably more critical now than previously because today's engineers are often expected to make significant design decisions before any product testing can be done. This reality of industrial practice, where engineers fuse computer modeling and physical intuition with design and analysis, challenges the modernization of curricula with respect to familiarizing students with computer-aided engineering software. Such software packages can be used for design, analysis, simulation, and manufacturing.

One difficult issue is the balance between traditional instruction of "engineering science" content and the exposure to computer-aided engineering software packages and their interfaces. We take it as an axiom that the exposure of students to problem-solving using computer-aided engineering (CAE) software should be increased without sacrificing the fundamental course content that is the mainstay of engineering curricula. We have found that self-paced and web-led CAE tutorials are a useful means for balancing traditional content and training on CAE software (in particular, Pro/ENGINEER Wildfire, ANSYS, Solidworks, Adams, and Matlab). In this paper, we discuss web-based modules for a variety of mechanical engineering courses. The intention of the effort is for students' use of the software packages to be transparently overlaid onto a traditional lecture-based curriculum. In the following sections, we discuss their usage in a required introductory course at the freshmen level and in required and elective courses offered to sophomores, juniors and seniors.

CAE Projects in a Freshmen-Level Mechanical Engineering Course

In 1991, Carnegie Mellon instituted major changes in its curriculum for first-year students in the college of engineering. In particular, first-year students began enrolling in discipline-specific introductory engineering courses[1]. Rather than expose first-year students to engineering through seminars or a course which would survey all of the traditional fields, the alternative approach was taken in which each engineering department began offering a core introductory course. Engineering students complete two such courses during their first year, and after having been thus exposed in some depth to two fields, students declare a major. In 1996, a semester-long team experience in computer-aided design, analysis and manufacturing was incorporated into the introductory mechanical engineering course using web-based tutorials. Our experience in teaching the course "Fundamentals of Mechanical Engineering" is that early exposure to computer-aided engineering can have a major impact on the perception that first-year students have of the mechanical engineering profession. Comments from students via course evaluations document that many students at this level are otherwise unaware that mechanical engineers use computers on a daily basis for design, simulation, and manufacturing operations.

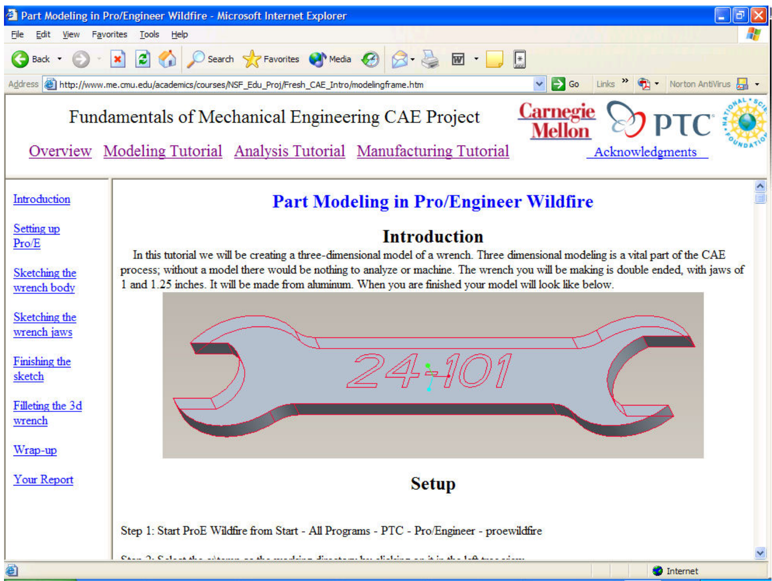

Figure 1: Screen shot of the introduction to the three-part tutorial sequence for modeling, stress analysis, and manufacturing of a wrench.

A web tutorial-led CAE project in the freshmen year is an ideal means for exposing students to design, finite element analysis, and machine tool programming, and to leverage students' natural interest in computer applications to motivate their study of engineering. Approximately 110 students enroll in the mechanical engineering course each semester, which carries a workload comparable to traditional first-year courses in mathematics and the sciences. As shown in Figures 1 and 2, the exercise used in the course has three parts:

- *Modeling*: Preparing the solid model and engineering drawing for an open-ended wrench.
- *Analysis*: Conducting a finite element stress analysis of the wrench including the steps of applying loads and boundary conditions.
- *Manufacturing*: Selecting tools for rough and fine pass cuts, and path planning, to machine the wrench from aluminum on a computer-controlled mill. The students are also given the option of producing their design in a rapid prototyping system.

In the end, each student walks away from the exercise with a wrench that he or she designed, analyzed, and fabricated without using paper, and through a process of seamlessly integrated computer software and hardware. In the analysis portion of the project, numerically-obtained stresses in the handle of the wrench are compared to those predicted on the basis of elementary beam bending equations. From the start, students are introduced to the concept of checking numerical results using "back of the envelope" calculations. The exercise is completed by some 220 freshmen students each academic year. Feedback demonstrates that students' changes in their perception of mechanical engineering as brought on by the this project have had a significant and favorable impact on their decision to choose mechanical engineering as a major.

Figure 2: Sequence of modeling, analysis, and manufacturing steps involved in completing the CAE wrench tutorials.

CAE Tutorials Across the Curriculum

Following the introductory exposure in the freshmen year, students continue to use self-paced CAE tutorials in the sophomore through senior years in both required and elective courses[2]. Links to all of the tutorials described in this paper can be found at the following web site address: http://www.me.cmu.edu/academics/courses/NSF_Edu_Proj/NSFOverview.html. Efforts are also underway to add links for course descriptions, CAE assignments, and a list of skills developed in each assignment used with a tutorial. All information on the web site is available for use by instructors in mechanical engineering programs at other universities.

As shown in Table 1, web-based CAE tutorials have been developed for courses in different areas of mechanical engineering. In each case, the tutorials have been written through a collaboration of students and faculty members. Once students have mastered elementary tutorials, they are able to solve certain open-ended and unstructured engineering design and analysis problems.

Year	Course	Web-based Tutorial	Software	Reference
Freshmen	Introduction to Mechanical Engineering	Integrated Exposure to Computer-aided Design, Analysis, and Manufacture	Pro/ENGINEER Wildfire	3
Freshmen	Introduction to Mechanical Engineering	Slider-crank Mechanism Motion Simulation	Adams	4
Sophomore	Statics	Tutorials for Statics	Solidworks	5
Junior	Dynamics	Motion Simulation Tutorials for Dynamics	Adams	6
Junior	Thermal-Fluids Engineering	Tutorials for Viscous Flow and Thermal-Fluids Engineering	ANSYS	7
Soph/Junior	Stress Analysis	Stress Analysis Tutorials	ANSYS	8
Junior	Dynamic Systems and Control	Tutorials for Dynamic Systems and Control and Feedback Control	Matlab	9
Senior	Design	Tutorials for Senior Design and Integrated Product Development	Solidworks	10
All	Graphics	Short Course Tutorials for Engineering Drawings	Pro/ENGINEER Wildfire	11

Table 1: Summary of web-based CAE tutorials in mechanical engineering.

Finite Element Tutorials for Sophomore- and Junior/Senior-Level Stress Analysis Courses

One series of tutorials developed for use by students after the freshman year involves use of ANSYS finite element software for stress analysis[7]. These tutorials are used in a required course in the sophomore year which combines strength of materials with an introduction to more sophisticated stress analysis, and in an elective course taken primarily by juniors and seniors. The elective course builds on the required course, covering topics that include the equations of elasticity, finite element methods and fracture mechanics.

The stress analysis tutorials currently consist of five problems for students to solve: A Plate Under Uniform Loading, A Beam Under 4-Point Bending, A Plate with a Hole, Analysis of a Bicycle Pedal Crank and A Double Edge-Cracked Plate. These problems cover a full range of modeling sophistication. However, each problem is presented via the same set of high-level steps, including Specifying the Geometry, Applying Boundary Conditions and External Loads, Refining the Mesh and Interpreting the Results. The goal is to give students a feel for the major steps needed to construct and interpret a finite element model, independent of the model details.

Because the first problem is simply that of a plate under uniform uniaxial tension, its emphasis is on obtaining a first introduction to the software interface, accurately setting up the problem and extracting known results. Using this easily understood problem, the concepts of linearity and use of symmetry conditions are also introduced. The beam bending problem is another example where strength of materials students can analyze a problem that they can easily interpret using handwritten calculations they have learned in class. Contour plots generated in this problem are an ideal means for demonstrating St. Venant's principle, which can otherwise be difficult for students to grasp.

Figure 3 shows a screen shot from Problem 4: Analysis of a Bicycle Pedal Crank (the component that links the bicycle pedal to the crank shaft). This tutorial includes a link to an ANSYS database file (a full analysis results file) for this problem for the student to download. Emphasis is then placed on student use of the ANSYS postprocessor and interpretation of the results that it provides. The model is of a loaded crank in the horizontal position, so that the crank is subjected to bending, torsional and shear loadings. The roughly rectangular shape of the crank makes it an excellent platform for introducing the torsion of non-circular cross sections in the elective course.

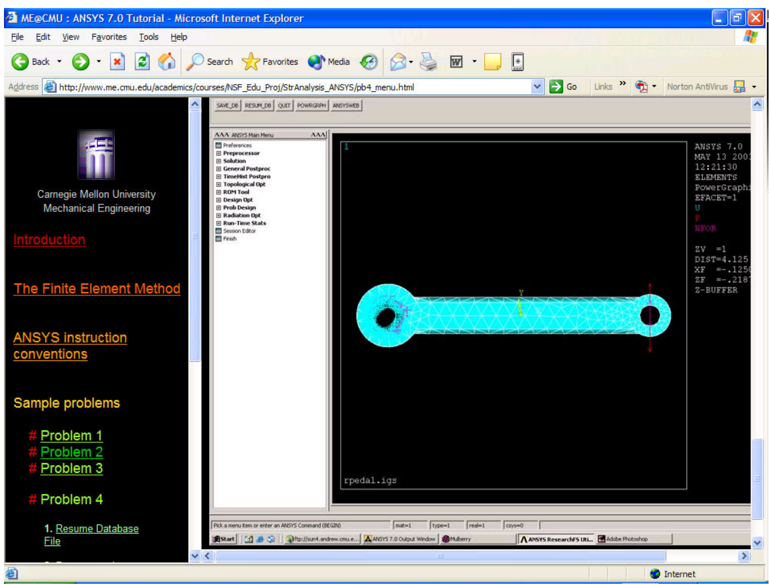

Figure 3: Screen shot of the stress analysis tutorial for a bicycle pedal crank.

Summary

Web-based tutorials and short courses have been developed to expose mechanical engineering students to various computer-aided engineering packages, and these have been implemented in courses across the curriculum from the freshmen through senior years. Because the tutorials are self-paced and can be completed with little or no supervision by instructors or teaching assistants, they generally encroach little on classroom time and a course's emphasis on traditional engineering science topics. On the other hand, we have found that student familiarity with the software packages and their interfaces can be useful on several fronts. First, lecture derivations and instruction are by their nature restricted to idealized geometries, and those concepts and models can be reinforced by providing students with tutorials on more realistic situations encountered in engineering. For instance, students can perform double checks of the computer simulations using the idealized models developed in lectures. Second, the computer-aided engineering tutorials provide students with a means to visualize complex motions or geometries. Third, the tutorials provide students who are interested in computer simulation, and those who are interested in project work, with an alternative learning format that can improve their interest and motivation[12].

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Pro/ENGINEER Wildfire, ANSYS, Solidworks, Matlab, and Adams are trademarks of Parametric Technology Corporation, ANSYS Incorporated, Solidworks Corporation, The Mathworks Incorporated, and MSC Software Corporation, respectively.

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