

## **Synthesis of Teaching Tools in a Course in Mechanics of Composite Materials**

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<http://www.eng.usf.edu/ME/people/kaw/class/composites/>

### **Abstract**

This paper presents a synthesis of tools used in teaching a course in Mechanics of Composite Materials. These tools range from modern such as computer-aided instruction to traditional such as show and tell industrial tours. The effectiveness of using these tools in encouraging active and cooperative learning, developing critical thinking and in promoting simultaneous fundamental and applied understanding is discussed. The reader is given a template of tools he/she can use to complement their course instruction.

### **Introduction**

Courses in composite materials are fast becoming popular electives in undergraduate engineering education. Just a decade ago only a handful of universities offered a course in composite materials, and now many universities are offering several courses on different aspects of composite materials such as processing, manufacturing, micromechanics, structural and computational mechanics. The most common course offered is in Mechanics of Composite Materials.

The objectives of this course mainly are:

- Introduce processing, manufacturing, properties, advantages, drawbacks and

applications of advanced composite materials

- Develop micromechanics and macromechanical analysis of single layered materials made of fiber and matrix
- Develop fundamental relationships for predicting mechanical and hygrothermal response of multi-layered structures based on macromechanics of single layered materials
- Use above objectives to introduce material, stiffness and strength optimizations for designing laminated composite structures.

I first taught a course in Mechanics of Composite Materials in the Spring semester of 1988. I taught conservatively and traditionally in a typical “chalk and talk” style, also called “the sage on the stage” method. Students took three tests and a final examination, and that was what the course grade was based on. Homework problems were assigned but not picked for grading. Yes, the old adage of “*Teachers teach the way they were taught*” (Collins and Hastings, 1990) was ringing as true as ever.

But the rapid advances in PC technology, an inner desire to make this course a treat in my students’ educational training and meeting the market need for composite engineers were crucial in changing how I would teach this course. Over the last ten years and mostly over the last four years due to the exponential growth of the WEB, the changes have paid off. This course now is a model course in the College of Engineering at the University of South Florida.

In this paper, we will present the various tools that are currently in use for this course. We hope that the paper will direct and guide the readers to synthesize similar

tools in their engineering courses. However, before any further discussion, we want to make it clear that students do not want tools to supplement their course, but to complement their course. They want tools which give them a better understanding and application of the course material. Using tools only as a linear addition to the course material will simply overburden the student and create frustration.

## **Tools**

The anisotropic nature of composites make these materials exciting to learn about, but at the same time also present many challenges in teaching about them. Using techniques other than plain lecturing are instrumental in the success of teaching this course. The tools used in the course are both modern and traditional. We will discuss each tool and how it has changed the way the course is taught.

1. PROMAL: The modeling of the mechanical behavior of composites requires lengthy but simple algebraic manipulations such as matrix inverse, matrix multiplication and solution of simultaneous linear equations. Several software packages are available commercially for the mechanical analysis of composite materials (Gibson, 1993). Although many of the packages are well written, most of the programs emphasize only the macromechanical analysis of laminates, or may not be user friendly, or lack graphical and tabular displays, or most importantly may be cost prohibitive to students and universities. These drawbacks are the motivation behind developing a comprehensive, professional, graphical user interfaced and student-friendly (different from user-friendly!!) educational software called

PROMAL<sup>®</sup> (<http://www.eng.usf.edu/ME/people/promal/book.html#promal>) (Kaw, 1990; Kaw and Willenbring, 1998).

PROMAL (Program for Micromechanics and Macromechanics of Composite Materials), written in-house at the University of South Florida, was the first tool introduced in the course. It has been continually modified since the inception of its idea in December 1988, when a brilliant undergraduate Steven Jourdenias and I thought it was a worthwhile project to take on.

The year of 1989 was an “exciting” time in programming languages as Microsoft Quickbasic<sup>®</sup> was breaking new grounds in visual programming in “DOS”. I worked on developing “black box” subroutines for the course while Steven worked on the graphical user interface. It took us 16 months before we nationally published the first version of PROMAL in March 1990. Since then many students and I have worked on developing new modules for the program and on rewriting the software in its current Windows-based form using Microsoft Visual Basic<sup>®</sup> (<http://www.microsoft.com/vbasic>).

Using PROMAL, students can now instantly conduct numerous parametric studies in studying the effect of the constituent properties on the properties of a composite. Failure theories can be compared and applied to design composite structures. Various possibilities can be explored at the click of a few buttons to appreciate the difference between metals and composite materials.

Out of three classes per week schedule, I hold one of these classes per week in a computer laboratory where each student has a computer and a video output connected to the instructor's computer. This allows the students to first see an example done by me and

then conduct their own numerical experiments. They are learning actively. For me, with the availability of the software in classroom, I have answered many of the students' "what if" questions readily.

The availability of the computer for each student in the classroom laboratory becomes especially important near the end of the course where students design laminated composite structures (Kaw and Willenbring, 1998). Most problems posed to the class are open ended and students come up with several answers. Simple designs of pressure vessels and leaf springs do not take more than ten minutes to work out with the PROMAL program, which would otherwise take several hours by using a calculator.

The availability of PROMAL does not preclude the student's need to think as he/she need to understand the effect of various inputs to the program to meet the design specifications. At the end of each exercise, my students and I discuss not only the various design alternatives but also how and why we think differently.

2. Videos: Although the main emphasis of the course is on teaching the mechanics of composites, I spend the first month in the semester course on introduction to composites. Topics include applications, thermomechanical properties, manufacturing, advantages and drawbacks of various types of composites. These topics are complemented by showing professional videos such as "New Materials" (developed by Films for Humanities and Sciences), "Composites in Manufacturing" and "Tooling for Composites" (developed by Society of Manufacturing Engineers). A list and summary of these and other videos, and how to acquire them is at <http://www.eng.usf.edu/ME/people/kaw/class/composites/>

[video.html](#).

Also, a request letter sent in 1994 to about 300 companies associated with manufacturing, applications and testing of composites in United States generated several donations of videos showing manufacturing processes such as filament winding and pultrusion, testing procedures and design guidelines.

If a picture is a thousand words, a video is a thousand times over. The student sees real-life applications, step by step procedures and industrial settings of processing and manufacturing in small and large companies, where they may be starting their professional careers. Videos complement and reinforce the material covered in classroom presentations and text books.

3. Presentations: Presentation tools such as the Microsoft Power Point 97© have revolutionized the art of presenting materials. The information previously shown through hundreds of slides and transparencies can now be saved in one place but presented in several formats suited to the audience. One can include video clips although 10MB of space per minute of video may be prohibitive at this time. The instructor can also upload the presentations on the WWW for later review by students.

To protect you from infringing on copyrights of others, direct references can be made to WWW sites in this tool. Instructors interested in protecting their own material from being pirated can put their material via course management tools such as Web-CT that require a login id and password.

The logistics of showing a computer presentation may be a chore at times since one

has to tug along a lap top and multimedia projector to the classroom. The set-up time with the entire wiring can also be a demotivating factor. Since the setup can take 5-10 minutes, you may also need to teach in a classroom that is not being used in the class period before yours. However, many universities including the University of South Florida have set up instructional rooms for faculty who use modern technologies. The rooms are already equipped with multi-media, slide and overhead projectors, and TV-VCR setups. Faculty just need to bring their multi-media material to the classroom or download it through a local area network (LAN) or WWW.

4. Multiple Choice Tutorials: Multiple choice tutorials have been developed for each topic of the syllabus. Currently the tutorials are on the WWW (<http://www.eng.usf.edu/ME/people/promal/question.html>). Students are required to take this test until they get a grade of at least 90%. Each test is counted as a homework assignment. The test is instantaneously graded and an e-mail is send automatically to me regarding their grade. Students have commented that these are beneficial for reviewing the course materials. In addition, the tests pinpoint the particular deficiencies they may have in understanding of the material.

Currently the tests are developed by using the quiz management tools called RAGS (<http://stargate.jpl.nasa.gov:1084/RAGS/index.html>) which is available free of charge. Developing the tests is simple and is based on writing text files with questions, image files, correct response and feedback. You will however initially need the services of your system administrator to set up RAGS on your server, and also for setting up the Internet

address for your tests. Updates and additions are in your control and can be easily done through any text editor.

Better WWW course management software are available now in the market, including Top class (<http://www.wbtsystems.com>), Web in a Box (<http://www.madduck.com/index.html>) and Web-CT (<http://www.webct.com/webct>) to name a few. In addition to automatic scoring as in the RAGS system, you can have several formats such as short-answer format, matching two columns option, and even partial grading.

Use of these course management tools for simultaneous examination of a whole class is possible but we have found that in some cases the server system may be overburdened by as few as 20 students and lock up the system. In addition, students may not be able to skip questions to answer or change their answers later.

5. WWW Sites: There is a wealth of information on the WWW. Many companies dealing with composite materials have their web-sites full of information about manufacturing, properties and applications. This information is readily available but the amount of data and finding the relevant material can be overwhelming at times.

As part of the grade, I ask each student to find three WWW pages related to the course. However, the pages have to be specific and not general in its scope. Then they write an annotated bibliography about the selected sites. The information is then appended to the course web-site (<http://www.eng.usf.edu/ME/people/kaw/class/composites/links.html>). The list is diverse and includes a site devoted to armor suits such as bulletproof vests and an animated show of manufacturing processes. The list will keep

growing as more students take this course. For better use, the list is currently being updated to reflect its correspondence to the course syllabus.

This exercise of finding relevant sites is an excellent example of encouraging active learning where students give up their traditional passive roles of listeners and actively construct knowledge. Students find new ways of finding and presenting information. By annotating the selected Web-sites, they are actively analyzing and commenting on the information.

6. Online Discussion Groups: To promote a better understanding of the course, I initiated an online discussion group using WebCT. The response of the discussion group was slow because there were only ten students registered in the last semester. This does need the old but proven motivation tool of making the student work – make it as a part (10%) of the final grade.

To avoid students posting obligatory questions just for the sake of getting a grade, I posed a question on the discussion group at the end of each chapter - “Ask three questions you were afraid to ask in class”. Although in the beginning some of the questions were “What is on the test from this chapter?” and “Are we allowed to bring a sheet of formulas to the test?”, these humorous questions are still allowed but not counted toward the three questions. As a good lawyer, I also rephrased my question as “Ask three conceptual questions you were afraid to ask in class”.

The questions asked by many students were quite thought provoking for the students as well as me. I also got an assessment of their preparedness. For example, I

found a few students struggling with the concept of principal stresses (<http://www.eng.usf.edu/ME/people/kaw/download/mohrcircle.zip>) and its relation to composite materials where stresses along the material axes are used to develop failure criterion. Another challenging concept included the use of strain gage rosettes and their relation to the stress-strain state in a lamina. Both of these concepts were excellent platforms to review mechanics of materials and then discuss the difference between isotropic and anisotropic materials.

Many specific questions such as the dynamic effect of environment and processing conditions sent me to the library and were an educational experience for my students and myself. Most of the questions and answers asked in the discussion group are compiled and posted on the WWW for future students.

It is expected that this information and clarification will make learning about composite materials more open and simple for future students. For current students, through this peer interaction, they learned from each other and formed skills needed for teamwork. I only acted as a facilitator (“guide on the side”) in the discussion group.

7. Mathematical Packages: Most students now have access to a variety of mathematical packages such as Maple™ (<http://www.maplesoft.com>), Mathcad™ (<http://www.mathcad.com>) and Mathematica™ (<http://www.mathematica.com>). However, I firmly believe that students should work problems first by hand. Most homework problems were required to be done by hand and a nonprogrammable calculator. A programmable calculator or a mathematical package was allowed only for conducting linear algebraic operations. Only

for the last two topics of the course on analysis and design of laminated structures, students were allowed to use any tools they want.

Mathematical packages are also useful in conducting symbolic manipulations where closed form solutions are more illustrative. One such example includes evaluation of linear thermal expansion coefficient of a polymeric unidirectional composite as a function of fiber and matrix properties (Kaw, 1993). What better way to prove that the transverse coefficient of thermal expansion of a polymeric matrix composites can be more than that of the matrix only if certain inequalities between elastic moduli of the fiber and matrix are satisfied and also that these inequalities are independent of thermal expansion coefficients of the fiber and matrix.

8. Q & A Style of Teaching: Since composites are such a vast field, I teach the introductory chapter in the course using a newspaper question-answer style (Kaw, 1997 – <http://www.eng.usf.edu/ME/people/promal/book.html>). Although many of my colleagues were skeptical of this "USA-Today™" approach, students have shown great appreciation for this style. They learn faster and like the progressive style of questions. This format also makes it a prime candidate for browsing on the WWW pages. New questions can be easily added and answers can be updated readily.

9. Tests: Even with the use of new technology, the emphasis on testing the student's knowledge about fundamentals has not changed. All tests are closed book type and only nonprogrammable (but scientific) calculators are allowed in the test. Although these

restrictions draw initial criticism from students, it is evident later (for many after graduation) to them that I want them to simultaneously gain a fundamental as well as application knowledge of composite materials.

The final examination (<http://www.eng.usf.edu/ME/people/kaw/class/composites/design.html>) is a take-home design project where the student design laminated composite structures, such as pressure vessels, drive shafts, etc. using any available design tools. These include handbooks, material databases, mathematical packages such as MATHCAD™ and MAPLE™, and design software such as PROMAL™.

10. Tours: Midway through course, students get to visit local companies that make composite materials products. The timing of the visits works very well since it reinforces the fundamentals learned in the classroom but also gets them to be enthusiastic about the designing of composites. Most of these companies are small companies (10 to 100 employees) who design, manufacture and test composite structures from the prepregs. Many of the manufacturing processes use hand-lay up. The students hence get to see the development of the product from beginning to finish.

### **Concluding Remarks**

The synthesis of various tools used in a course in Mechanics of Composite Materials is discussed. The incorporation of all the above tools does require a significant cost of time in the beginning. However, the main point to remember is that one does not need to include all of the above tools at once. It can be quite overwhelming to do so even

if you do not have significant research and scholarly obligations. The key to success is choose one tool at a time, which you think will be effective, incorporate it and monitor its benefits.

Smaller classes are excellent avenues for experimenting with the process. I welcome any comments from the reader as I will be glad to answer any questions that you may have about my experience in teaching the Mechanics of Composite Materials course (<http://www.eng.usf.edu/ME/people/kaw/class/composites> or [kaw@eng.usf.edu](mailto:kaw@eng.usf.edu)).

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