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WEB MODULES LINKING MECHANICS AND MATERIALS SCIENCE

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ABSTRACT

In 1996, the MIT subject 3.11 Mechanics of Materials in the Department of Materials Science and Engineering began using an experimental new textbook approach, written with a strongly increased emphasis on the materials aspects of the subject. It also included several topics such as finite element methods, fracture mechanics, and statistics that are not included in most traditional Mechanics of Materials texts. These nontraditional aspects were designed to fit the curriculum in Materials Science and Engineering, although admittedly Mechanics instructors in other departments and schools might not find all of them suitable for their own subjects. Further, a number of topics may be of interest in educational curricula and industrial practice outside traditional Mechanics subjects.

One approach to increasing the flexibility and adaptability of this materials-oriented text is to make discrete and coherent portions of it available as stand-alone, web-available modules. Instructors could then pick and choose among topics, and assemble a subject offering in whatever way they choose. It would also be possible for instructors of specialty engineering subjects, for instance bridge or aircraft design, to add modules on mechanics of materials aimed at their own needs.

A series of such modules are now being developed under a National Science Foundation Course, Curriculum and Laboratory Improvement (CCLI) grant aimed at strengthening the links in the engineering curriculum between materials and mechanics. Each module is intended to be capable of standing alone, so that it will usually be unnecessary to work through other modules in order to use any particular one. This approach will be outlined and demonstrated, both as an approach to the specific topic of a mechanics-materials linkage, and as a possibility for more general implementation in distance learning.

Keywords: *Web modules; Mechanics and Materials Science*

INTRODUCTION

Most engineers are involved in *design*, and they generally design articles of commercial importance using selected *materials*. (Software engineers might be an exception.) University curricula in engineering are aimed at providing the underlying fundamental knowledge needed in design work, and often try to teach or at least provide some experience in aspects of the design process itself. In the case of load-bearing structural items, design requires at least two major disciplines: *mechanics*, the primarily mathematical description of the stresses and strains induced in an object by applied loads; and *materials*, the description of how the material will respond to these stresses and strains.

Structural engineering students encounter the mechanics aspect of mechanical design in a sophomore or Junior-level subject usually named Mechanics of Materials, using texts such as those of Beer and Johnston[1] or Gere[2]. These texts usually follow the approach pioneered by the great mechanics educator Stephen P. Timoshenko (1878-1972)[3], and deal principally with stress analysis of simple structures assuming linear elasticity. Most of these traditional texts are of fine quality, although over the years they have become considerably larger than can be covered in a single term. Further, they have little coverage of the relations between the material's mechanical response and its chemistry or microstructure, nor do they deal much with softer, anisotropic and time-dependent non-metallic materials now becoming increasingly important in biomedical design and other newer aspects of engineering practice.

It is common in engineering curricula to require students to take a subject in Materials Science, using a text such as that of Callister[4] or Shackelford[5]. This, along with core chemistry and physics subjects, is intended to supply a sufficient coverage of the materials aspects of structural analysis and design. Unfortunately, only a small fraction of the syllabus typically covers topics dealing with mechanical response. This leaves the student to discern the linkage between these two aspects of mechanical design, and it is easy to perceive the materials and mechanics subjects as unrelated entities. This leaves the materials subject as an "academic promontory," with structural engineering students wondering why they had to take it.

The situation in materials departments is somewhat inverted in comparison with the structural disciplines. At MIT, the School of Engineering has eight departments, and only the Department of Materials Science and Engineering (DMSE) does not have a "materials subgroup" within it. In DMSE, materials is the "main group," and mechanics is a subgroup. Similarly, DMSE students are strong in the materials aspects of engineering, but perhaps weaker in aspects of stress analysis and mechanical design. Materials graduates need competence in mechanics in order to design correctly with their carefully developed materials, and some materials departments address this need by requiring a traditional Mechanics of Materials subject taught by one of the structurally-oriented departments (typically Mechanical, Civil, Aerospace, or Applied Mechanics). If the connection between the mechanics subject and the materials curriculum is unclear, the mechanics subject then becomes the academic promontory.

Recently, several educators in both Mechanics and Materials departments have argued[6] that the separation of these two subjects as they often occur in the curriculum is excessive and unnatural, and that a stronger linkage between the two disciplines would improve both institutional efficiency and student learning.

A MATERIALS-ORIENTED MECHANICS SUBJECT

As elaborated in an extensive review conducted by the National Research Council[7], Materials Science and Engineering is a study of theoretical and experimental relations among the following entities:

- A material's *processing*, to include its chemical synthesis as well as subsequent thermomechanical treatment and shaping,
- The material's *microstructure*, as arising from its processing,
- The material's *properties*, arising from its microstructure, and
- The material's *performance* in an engineered structure or product, as dictated by its properties.

Traditional mechanical design employs principally the last two steps, using handbook material properties in selection and sizing to develop a product. This approach has worked for millennia, but is increasingly inefficient as designs come to employ modern materials whose processing and resulting properties are themselves an adjustable part of the design process. A stronger linkage between Mechanics and Materials would increase the coverage of the first two steps – processing and microstructure.

The Department of Materials Science and Engineering at MIT is large enough to offer its own Mechanics of Materials subject, and this subject naturally seeks to blend the materials and mechanics aspects of the discipline. A text for the subject has been written with this perspective[8], and has been used for approximately the past five years. The text was assembled from years of experience in teaching this subject, and follows the day-to-day teaching syllabus. It was intended from the first as a teaching text, rather than a general technical reference. It includes some topics that usually cannot fit into the time constraints of a single term, in order to allow for student exploration and flexibility in tailoring the syllabus from year to year, but not many. The text is therefore much smaller than the Timoshenko-style standard texts. The text also progresses gradually from elementary to relatively advanced mathematical formalisms, and moves along the stress-strain curve from linear elastic and viscoelastic response, to rubbery elasticity, to yield and finally to fracture.

Strong links between materials and mechanics are sown throughout the text: the atomistic mechanisms underlying material property descriptors such as Young's modulus and Poisson's ratio are explained, often in substantial detail. Yield and fracture, topics not always included in introductory texts, are explained both in terms of their formal solid mechanics (yield criteria, stress intensity factors, etc.) and their materials aspects (crazing of polymers, effect of grain size on fracture toughness, etc.). This linkage provides a treatment that is both rich academically and very practical. Unfortunately, it is also a substantial departure from traditional mechanics texts, and some instructors have been reluctant of to embark on such a venture. This is an impediment we have sought to overcome by making the text content available as web modules.

WEB-BASED INSTRUCTION

The remarkable growth of web and other computer network technologies has added a large number of potential tools to the engineering educator's arsenal. This community is not of one mind regarding how best to use these new tools, and we are currently in a period of exciting experimentation. At the least, the web can provide an efficient means of administering subjects, for instance in publishing the syllabus and keeping the class grade list (coded to preserve confidentiality) up to date. It can also provide links to supporting auxiliary material, such as film clips of actual designs and laboratory experiments. The web page for the 1999 MIT/DMSE Mechanics of Materials subject may be found at the URL http://web.mit.edu/course/3/3.11/www/; this is a modest but useful web implementation for teaching. It uses very plain HTML constructs, without the need for page design software.

Many engineering educators feel the web and other such technologies will augment rather than replace traditional lecture-and-chalkboard methods. The seemingly tedious method in which students copy material as the instructor chalks it onto the board seems to transmit technical information at approximately the right pace for comprehension, and using transparencies or web pages to speed things up can easily produce information overload. Further, engineering faculty have come to realize that preparation of even marginally complicated web presentations is very time consuming, and involves a set of skills they do not necessarily have or wish to develop.

The easy availability of web pages, however, does promise a possible remedy to an admitted difficulty with the materials-based approach to Mechanics in the existing MIT/DMSE text. Since the approach is novel and nontraditional, it may be difficult for faculty to swallow it all at once. A more flexible approach, now being implemented under NSF sponsorship, includes rewriting the text's topics as discrete web-available modules (see http://web.mit.edu/course/3/3.11/www/modules.html). This would permit an instructor to use only those portions she finds effective for the current term, without being locked into a new book. Such a modular approach might be useful in many subjects beyond Mechanics or even engineering. Almost no one finds a text perfectly matched to their particular needs, and the availability of easily-available modules of textbook quality would allow each instructor to tailor-make a text for her own desires. Problems with copyrights and payments arise, but if the value and demand are there these could certainly be overcome.

WEB MODULES

As stated above, the web provides an easy way to make content available at the click of the mouse, and the web page displayed in Figure 1 shows the simple layout used in publishing the MIT/DMSE Mechanics modules. This is basically the table of contents of the printed text, broken out as a series of web-selectable units.

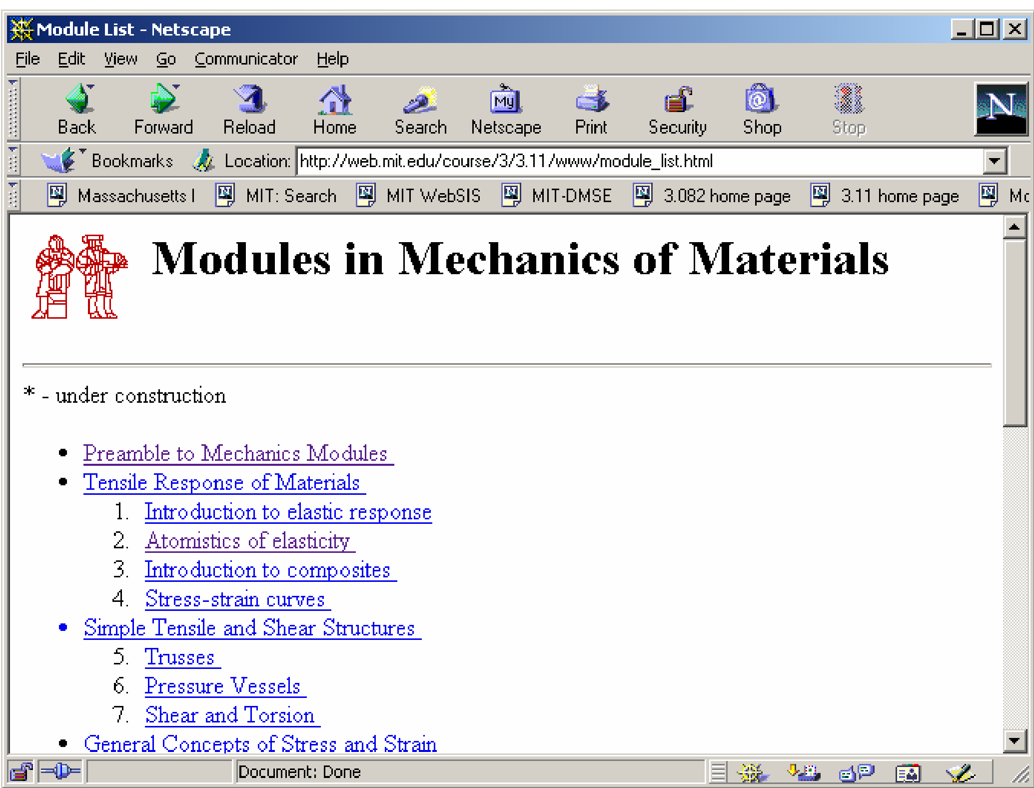

Figure 1. Snapshot of a portion of the main Mechanics Module list.

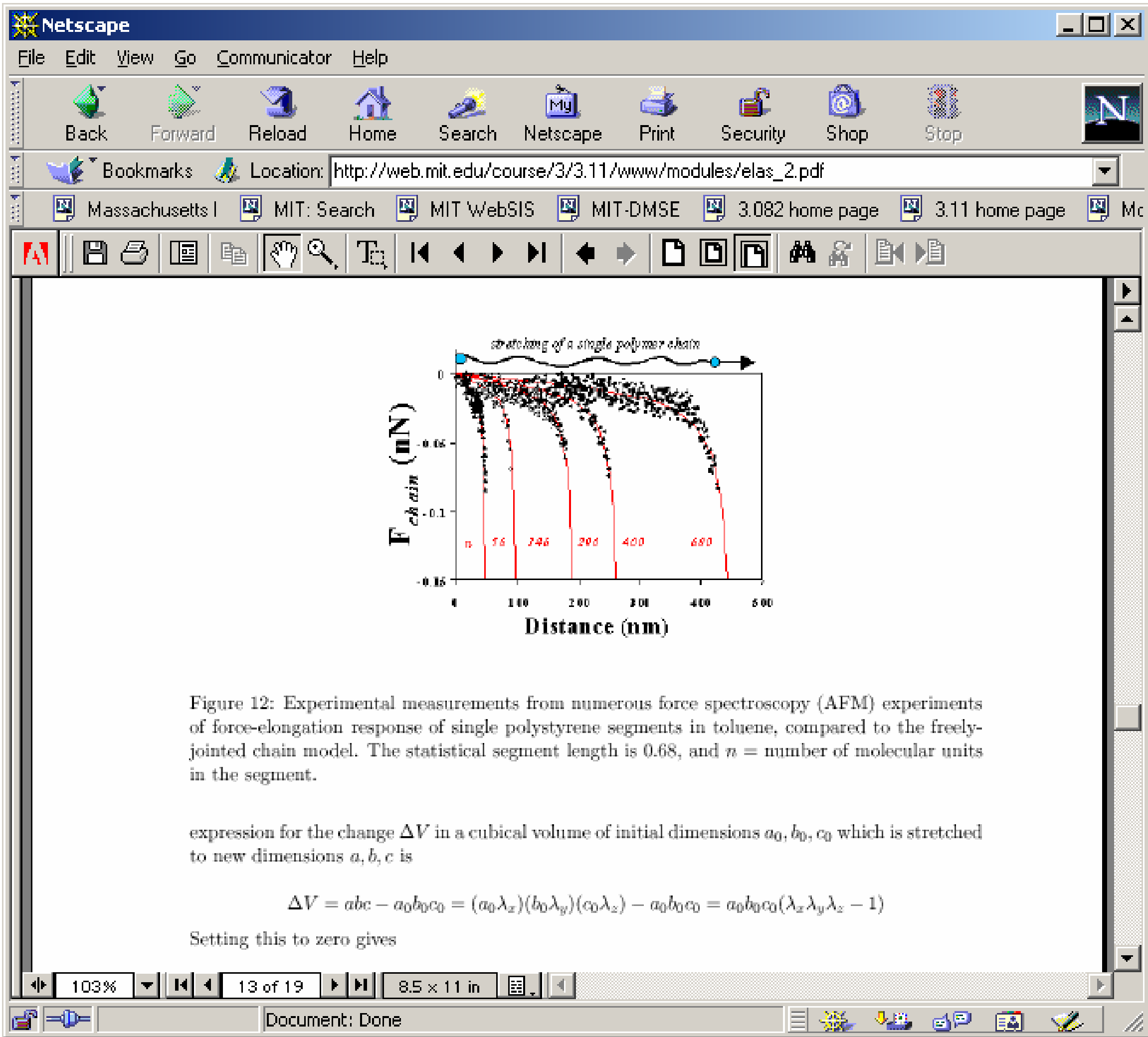

Figure 2. Web snapshot of a portion of a LaTeX/pdf module page. This page, part of the module on atomistics of elasticity, is typical of the many links between solid mechanics and materials science.

In these modular presentations, it was felt that HTML authoring tools are not yet of sufficient flexibility and quality for high-level technical content, including extensive equations and figures. For this reason, LaTeX was used to generate postscript and then pdf files that could be read with Adobe Acrobat, easily available on most web browsers. A portion of a page from the module "Atomistics of Elasticity" is shown in Figure 2 as an illustration.

These pages can be viewed on screen, but the principal intent is that they be printed by the instructor and distributed to the class. Most students prefer hardcopy for its ease of use and flexibility, and it is economic for the instructor to use low-cost photocopying, as opposed to having each student tie up network printers.

CONCLUSIONS

Instructors in engineering curricula should consider developing a stronger link between materials concepts and subjects in Mechanics of Materials; this could strengthen student understanding in both of these closely related disciplines. Most existing texts are not written with this coupling in mind, and Mechanics instructors wishing to introduce more materials content in their subjects might explore some of the modules described in this paper. The authors would welcome comment and feedback regarding any improvements readers might wish to suggest.

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REFERENCES

1. F.P. Beer and EA.R. Johnston, *Mechanics of Materials*, 2nd ed., McGraw-Hill, New York, 1992.
2. J.M. Gere, *Mechanics of Materials*, 5th ed., Brooks-Cole, Pacific Grove, CA, 2001.
3. S.P. Timoshenko, *History of Strength of Materials,* McGraw-Hill, New York, 1953. Available from Dover Publications, New York, 1983.
4. W.D. Callister, *Materials Science and Engineering – An Introduction,* 3rd ed., J.Wiley, New York, 1994.
5. J.F. Shackelford, *Introduction to Materials Science for Engineers*, 4th ed., Prentice Hall, New Jersey, 1996.
6. D. Roylance, C.H.M. Jenkins and G.E. Dieter, *"The Materials-Mechanics Linkage in the Engineering Curriculum," Journal of Materials Education* 21, 145-148 (1999).
7. Committee on Materials Science and Engineering, National Research Council, *Materials Science and Engineering for the 1990s: Maintaining Competitiveness in the Age of Materials*, National Academy Press, Washington, D.C., 1989.
8. D. Roylance, *Mechanics of Materials,* J. Wiley, New York, 1996.