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The Introductory Materials Science and Engineering Course

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ABSTRACT

The introductory materials science and engineering course offered at the college/university level is, for many instructors, very difficult to design and to teach. This presentation discusses challenges for the course, as well as several problematic issues to include: course content, course organization, and course mechanics. The results of two surveys of engineering faculty are presented and discussed; these provide perspectives and lead to suggestions on how to manage these troublesome areas, and improve the quality of and student satisfaction in this course. Also discussed are commercially available software packages, and, in addition, a hybrid electronic-paper introductory materials textbook.

INTRODUCTION

One of the most pressing challenges for undergraduate education in the discipline of materials science and engineering is the teaching of introductory courses. The majority (about 85%) of introductory courses are of one semester/quarter duration, and there is the perceived expectation that all of materials science and engineering should and can be "covered." This situation is something akin to having, say, a single introductory mechanical engineering course that presents the fundamentals of statics, dynamics, strengths of materials, thermodynamics, etc.

It has been the author's experience that there is considerable student dissatisfaction in a high proportion of these introductory courses. Common complaints include: "the instructor rushes through the subject matter too rapidly;" "the course is not interesting;" "I don't see any relevance to what I'm supposed to learn in this course;" and "the instructor is very disorganized." Consequently, one of the ongoing struggles for MSE departments is deciding what can and should be done to improve course quality and enhance student satisfaction. A variety of scenarios have played out as MSE departments confront this ongoing problem. In some instances the introductory course is a service course for non-MSE majors. And when student dissatisfaction is rampant, other departments opt to design and teach their own courses. This situation, of course, may have adverse funding consequences to the MSE department. On other occasions, the MSE department assigns one of its weaker instructors to the service course (perhaps as a punishment, and/or to reduce this instructor's exposure to its own MSE students).

There are several elements of the class and subject matter in the introductory course that make it difficult to teach; these include the following:

(1) Inhomogeneity of class composition—student major and class standing.
(2) The number of MSE topics is overwhelming.
(3) Course content—including the dilemma of breadth-versus-depth coverage.

(4) Course organization.

(5) Mechanics of course management—generating student interest and providing relevance.

This paper offers some perspectives, insights and suggestions on how to deal with most of the above issues in order to improve the quality of and student satisfaction in an introductory MSE course.

The author offers no claim to be the model or an expert with regard to teaching the introductory course. Rather, any credibility comes from associations and conversations with a large number of MSE faculty, and feedback/suggestions on several editions of an introductory level materials science and engineering book that he has written.

ENGINEERING FACULTY SURVEYS

The author's publisher recently commissioned two surveys of engineering faculty in the US and Canada regarding the introductory materials course. Objectives of these surveys were threefold—to solicit information relative to: (1) textbook issues, (2) the character of specific courses, and (3) the respondents' feelings about course content, organization, usage of electronic media, etc. The first survey was conducted by mail in the fall of 1998, with 141 respondents; the second took place in the fall of 2001 via the web, and 80 faculty participated. Results of these surveys shed light on how to address some of the introductory course problems and issues, as discussed below.

STUDENT COMPOSITION

One significant challenge of teaching some introductory courses involves a student population that is inhomogeneous, relative to both class standing and major. It is not uncommon to find sophomore through senior level students in the same introductory course. (Students in other engineering disciplines dread this course, and often delay taking it until the final semester of their senior year.) The obvious problem here is that students enter the introductory course with varying degrees of academic preparation and intellectual maturity; consequently, it is difficult for the instructor to present the material at an appropriate and acceptable level for all students. When the course material is "dumbed-down" for the benefit of the least prepared students, the more advanced students become bored. Conversely, sophomores become lost when the level of presentation is tailored to seniors. Probably the best way to handle this type of situation is to direct the course at some intermediate level in an attempt to accommodate the greatest number of students.

Another critical issue relates to course content, in that there should be some correlation between the MSE principles/concepts discussed in the course and those topical areas that are relevant to the students' engineering discipline(s). Of course, there is some disparity of desired topical content from one engineering discipline to another. Mechanical engineering students should have some mastery of mechanical behavior and failure, whereas concepts of electrical and optical properties should be addressed for students majoring in electrical engineering. Thus, what does an instructor do when students from more than one engineering discipline are enrolled in his/her course? This issue will be treated in detail in the following section.

COURSE CONTENT

With regard to introductory MSE course content, there are two issues to consider: (1) what subject matter to cover and (2) whether in-depth coverage should take precedence over breadth coverage, or vice versa. Of course, these two issues are not mutually exclusive. For example, the degrees of detail of topical discussions will affect how many topics may be covered. And, it goes without saying, that there is a vast number of topical areas in materials science and engineering, and it is simply impossible (and foolish) to try cover the entirety of the discipline, even on an introductory level, in a single course. In fact, such a feat would be difficult in even a full-year course.

As a textbook author, the issue of content in terms of what and in how much detail is a major concern. Probably the most common complaint of adopters is that the textbook has too many pages; however, many are so bold as to suggest they have two or three pet topics, missing in the current text, that should be included in the next edition.

Several years ago, the author and his editor decided that issues relating to course content should be addressed in terms of textbook content. After some discussion, it was decided to propose that an introductory course syllabus consist of (1) a set of "core" topics to which all engineering students (irrespective of discipline) should be exposed (and hopefully understand); and (2) for each engineering discipline, a different set of what are termed "optional" topics.

Thus, it first became necessary to determine which MSE topics should be included in this core set. After further deliberation, it was decided that the best way to accomplish this goal was via a survey of engineering faculty—the 1998 survey mentioned above. A questionnaire was prepared by the author, which included a list of approximately 50 topics that could be covered in an introductory MSE course; this list is presented in Table 1. Each respondent was asked to indicate whether each topic should or should not ("Yes" or "No") be part of the core set. The results are also presented in Table 1 as the percentage that responded "Yes" to each topic. Here it may be noted that the "Yes percents" (i.e., criticality ratings) ranged from a maximum of 99% to a minimum of about 60%. It is interesting to note that at least 60% of these respondents felt that all topics should be covered in the introductory course.

It was decided (arbitrarily) that any topic that received a rating of 90% or greater would be included as part of the core. Twenty of the topics fall into this category, which are listed in Table 2. Thus, from the results of this 1998 survey (i.e., by consensus of engineering faculty respondents), the author suggests that the introductory materials course for students of all engineering disciplines cover at least the set of "core" topics listed in Table 2.

The next step was to formulate a set of optional topics for each of the engineering disciplines. This was accomplished via interviews conducted by the author with a number of faculty members from the various engineering types. A list of those non-core topics from Table 1 was given to each interviewee, and he/she was then asked to indicate, which, in their opinion, should be covered in an introductory MSE course to taken by their students. These sets of optional topics are presented in Tables 3 through 6 for chemical, mechanical, civil, and electrical engineering , respectively. The consensus of materials science and engineering faculty members was that the introductory course for their students should be of two semesters (three quarters) duration, and that all of the topics listed in Table 1—both core and non-core—be covered.

Table 1 Listing of MSE topics included in the 1998 survey and, for each, the percentage of respondents that believe it should be included as part of the "core" for an introductory course.

Topic	% Yes	Topic	% Yes
Atomic structure	93	Kinetics, phase transforms.	89
Atomic bonding	94	Corr. of properties	
Structures	98	to micrstructure	95
Metallic	99	TTT Diagrams	94
Ceramic	96	CCT Diagrams	86
Polymeric	98	Recovery, recrystalliz-	
Defects in crystals	96	ation, grain growth	94
Microscopy	67	Material types, properties,	
Dislocations	95	applications	95
Diffusion	93	Metal alloys	96
Mech. properties/behavior	98	Ceramics	92
Metals	98	Polymers	89
Ceramics	96	Construction materials	59
Polymers	96	Composites	85
Fracture	87	Materials fabrication/	
Fatigue	87	processing	73
Creep	87	Metals	68
Deformation mechanisms	92	Ceramics	62
Metals	90	Polymers	63
Ceramics	85	Composites	60
Polymers/elastomers	85	Semiconductors	59
Strengthening/hardening		Corrosion	81
techniques	92	Electrical properties	78
Metals	90	Optical properties	64
Ceramics	81	Magnetic properties	63
Polymers	81	Thermal properties	73
Solid state thermo. &		Case studies/design	
phase equilibria	79	examples	82
Phase diagrams	94	Economic/environmental	
Metallic systems	93	considerations	75
Ceramic systems	79		
Ternary systems	58		

In summary, the author suggests a criterion for selection of content for the introductory materials course: the coverage of set of core topics for all courses, plus suggested sets of discipline-specific optional topics.

Of course, this criterion does still not completely address a couple of important issues. One of these involves courses in which students are enrolled from more than one engineering discipline. The instructor still needs to decide which optional topics to cover. Perhaps this

Table 2. Suggested core topics (those receiving acceptance ratings of 90% or greater) for introductory materials science and engineering courses.

Atomic structure	Mechanical behavior—polymers
Atomic bonding	Deformation mechanisms—metals
Metallic structures	Strengthening/hardening—metals
Ceramic structures	Phase diagrams—metallic systems
Polymeric structures	Kinetics—TTT diagrams
Defects in crystals	Recovery/recrystallization/grain growth
Dislocations	Correlation of properties/microstructure
Diffusion	Metal alloy types/properties/applications
Mechanical behavior—metals	Ceramic types/properties/applications
Mechanical behavior—ceramics	Polymer types/properties/applications

Table 3. Suggested optional topics for chemical engineering students in introductory materials science and engineering courses.

Polymer structures II	Composites
Deformation mechanisms—polymers/elastomers	Corrosion/degradation
Creep/viscoelasticity	Thermal properties
Processing of polymers	Case studies/design examples
	Economic/environmental considerations

Table 4. Suggested optional topics for mechanical engineering students in introductory materials science and engineering courses.

Fracture	Strengthening/hardening—polymers
Fatigue	Composites
Creep/viscoelasticity	Corrosion/degradation
CCT diagrams	Case studies/design examples
Deformation mechanisms—Polymers/elastomers	Economic/environmental considerations

Table 5. Suggested optional topics for civil engineering students in introductory materials science and engineering courses.

Fracture	Corrosion/degradation
Fatigue	Case studies/design examples
Creep	Economic/environmental considerations
Composites	

Table 6. Suggested optional topics for electrical engineering students in introductory materials science and engineering courses.

Electrical properties	Optical properties
Thermal properties	Case studies/design examples
Magnetic properties	Economic/environmental considerations

problem may be resolved by using some combination of topic sets (Tables 3 through 6), to be weighted by class composition in terms of the types and proportions of engineering students.

Furthermore, the dilemma of depth-coverage versus breadth-coverage often needs to be addressed. Again, decisions of this type are normally made by the instructor. The above core-optional topic scheme, which provides direction as to what areas should be discussed, can help in these decisions.

Two outcomes of the second survey are interesting and worth mentioning. Respondents were asked to estimate the mean course time they spent discussing various topics—specifically material type and property type; results are presented in Tables 7 and 8. With regard to material type (Table 7), a significantly high proportion of time (greater than 50%) was spent on treating metals and metal alloys. (Unfortunately data on electronic materials were not collected.) Furthermore, mechanical properties were discussed more frequently than electrical, thermal, magnetic, and optical properties (Table 8). This is not unexpected inasmuch as the majority of students in introductory materials classes are in mechanical/aerospace engineering programs.

COURSE ORGANIZATION

In a general sense, the introductory materials science and engineering course deals with the different material types (i.e., metals, ceramics, polymers, composites), as well as the various kinds of properties exhibited by materials (i.e., mechanical, electrical, magnetic, etc.). Therefore, when one considers course organization, two basic approaches are possible. For one,

Table 7. Percent class time spent discussing various material types (2001 survey).

Material type	% Class time
Metals	30
Metal alloys	25
Polymers	13
Ceramics	12
Composites	8

Table 8. Percent class time spent discussing various property types (2001 survey).

Property	% Class time
Mechanical	47
Thermal	11
Electrical	10
Magnetic	6
Optical	8

the structures/properties/processing techniques/applications are treated by material type. This is sometimes termed the "traditional" or "metals first" approach inasmuch as structures, diffusion, mechanical properties, phase diagrams, etc. are normally first discussed for metallic systems; subsequent chapters deal with these same topics, for ceramics and then for polymers.

Conversely, with the alternative approach, the three basic material types are discussed together in terms of first their structures, and then, one at a time (but not necessarily in the order of), specific property types, processing techniques, and possible applications are treated. Some refer to this as the "integrated" approach, since discussions are integrated relative to the different material types. Probably no single course is organized as purely traditional or integrated; however, one or the other normally predominates.

There are pros and cons for both of these approaches, and it is not the author's intent to favor one or the other.

The main strength of traditional is that student understanding is facilitated (1) when fundamentals/principles are first presented in the context of structurally simple (i.e., metallic) systems, and when subsequent discussions involve increasingly more complex (i.e., ceramic, polymeric, and composite) systems; and (2) in many instances more examples exist for metals and their alloys. Furthermore, some instructors argue that with this traditional approach there tends to be too much emphasis placed on metals, and that students should realize that the other material types are also important.

With regard to the integrated approach, the prime advantages often cited are (1) students come to realize and appreciate differences in the characteristics and properties of the various material types; and (2) when considering properties and processing, all material types should be included. However, many instructors find that the subject matter tends to be more fragmented with this integrated approach than with the traditional one.

In the 2001 survey, about 20% of the respondents indicated they used the integrated approach. However, about 35% of the remaining respondents indicated they might be interested in using it.

Of course, the suggested core-optional topics course content scheme, as described above, may be implemented in both traditional and integrated formats.

COURSE MECHANICS

Students are more motivated to become involved in the teaching-learning process (1) when they find the classroom experience interesting, and (2) when they perceive that learning and mastering the subject matter presented will have some value and be of benefit to them. Probably the greatest challenge for an instructor is to decide what can be done to enhance the perception of relevance and to generate student interest. Course organization and content will have some influence on these issues. However, what transpires in the classroom, or the mechanics of the course, will probably have even a greater impact.

Numerous presentations at this and other conferences in the past have dealt with classroom activities, demonstrations, projects, etc. that may be used to enhance relevance and student interest; and it is not the intent of this paper to provide much by way of suggestions in these areas. It should be noted, however, that the prime responsibility for making the course relevant and interesting remains with the instructor, and that any textbook that is used (as well as accompanying instructors resource materials) can and will play only a minor role. Some introductory textbooks provide relevance in the form of case studies. Most case studies discuss the rationale behind why specific materials are employed in familiar components or applications in terms of properties, ease of fabrication/processing, etc. For example, one case study often found in introductory materials texts discusses materials that are utilized for the outer surfaces of the Space Shuttle Orbiter. A variation of this case-study approach is that of “reverse engineering” whereby fundamental principles and concepts are presented from the perspective of “real-world” applications—e.g., the heat treating of bicycle spokes in terms of continuous-cooling transformation diagrams.

ELECTRONIC AND SOFTWARE ISSUES

In order to assess interest in electronic texts, the author and his publisher recently (December 2000) published an alternate hybrid print-electronic version. The entire book (approximately 875 pages) is on CD-ROM, whereas core topics (as detailed above), equivalent to about 525 pages, also appear in print. For the CD-ROM component, all book elements are electronically linked to facilitate navigation. Furthermore, this new hybrid version is organized using the integrated format, whereas the original version was according traditional. A number of adopters of this new version were surveyed, as to theirs and their students' experiences and impressions. Most of them preferred the integrated organization over traditional. Reviews were mixed relative to print versus electronic. In the majority of cases, students and/or the instructors found navigation of the electronic elements somewhat awkward and preferred not to read multiple pages from the computer monitor. Consequently, these instructors desired to have in print, all of their course materials. The publisher has provided to them, printed copies of those topics presented in their courses, which are only on the CD-ROM.

In both the 1998 and 2001 surveys, interviewees were asked to comment on their use of electronic (web and/or CD-ROM) resources in their introductory courses. Those areas of significant interest were, for students, visualization (of structures), simulations, and demonstrations. Instructors tended to favor using these resources for class/lecture preparation, as opposed to course management—assigning and grading homework assignments.

There are several commercially available software packages that contain numerous visualizations and simulations (e.g., rotatable unit cells and polymer structures, atomic motion that accompanies diffusion, etc.). One or two are formatted as tutorials. Some of these packages are as follows:

"MATTER" (on CD-ROM) which was (and continues to be) developed at Liverpool University in the UK. It currently consists of 18 modules on a variety of topics (crystallography, dislocations, phase diagrams), which may be used as tutorials. The cost is about $US 60, and several demonstration modules may be downloaded from *www.liv.ac.uk/~matter*. Details about ordering are also found on this web site.

"Materials Science: A Multimedia Approach," by John Russ (also on CD-ROM) contains numerous visualizations, film clips, and tutorials. The cost is approximately $US45—ordering details are available at *www.thomsonlearning.com*.

"A Glossary of Materials Science Technology," by Charles McMahon (and supported by the NSF Gateway Coalition). This CD-ROM set consists of a glossary, animations, and videos that are presented in a tutorial format, and accompanies McMahon's book *Introduction to Engineering Materials: The Bicycle and the Walkman*. The book cost is about $US40, and the CD-ROM set comes gratis when an examination copy of the book is ordered. Go to *www.lrsm,upenn.edu/bw/BW.html* for ordering details and to preview sample modules.

"CES4 EduPack," by Michael Ashby. This package is an extensive and comprehensive database especially useful for materials selection and design studies. It is composed of a variety of properties for a large number of engineering materials, and, in addition, cost and processing information. Available by site license. For details go to *www.grantadesign.com.*

"Interactive MSE" which accompanies and is bundled with the author's two introductory materials books. This package consists of eight interactive modules (e.g., crystal structures, dislocations, tensile tests, etc.), a materials property/cost database, and an equation solver. Details are available at *www.wiley.com/college/callister.*

THE INTRODUCTORY MATERIALS COURSE—A RECRUITING TOOL

One area of concern for many departments of materials science and engineering is that of the size of both undergraduate and graduate enrollments, which seem to be shrinking. Unfortunately, the materials discipline is not well known nor appreciated. However, one way of publicizing the discipline and recruiting students is through the introductory materials course. In many cases, it is a service course, taught by a materials department, and taken by undergraduate students from other engineering disciplines. When this course is taught effectively and student interest is generated, sophomore and junior level students may be attracted to and change their majors to materials. Furthermore, senior-level students who and plan to do graduate work may be persuaded to transfer into materials graduate programs.

Upgrading, updating, and fine-tuning the introductory course is an ongoing endeavor for the instructor. Unfortunately, in many cases extrinsic incentives (financial and time allotments) are not available; in such cases it is imperative for the instructor to be proactive in course development, and willing to settle mainly for intrinsic payoffs. Furthermore, it is hoped that materials departments will recognize the importance of their introductory courses, and endeavor to find the means to reward and recognize faculty who are committed to improving them.

SUMMARY

This presentation began by discussing those elements of an introductory materials course that make it difficult to teach—viz. inhomogeneity in terms of class composition, as well as the issues of course content, organization, and mechanics. For a course composed of students having different class standings, the level of the topic presentation may be pitched at some level intermediate between the most and least advanced students.

Relative to content and breadth-versus-depth topical coverage issues, it was proposed that the course syllabus consist of a set of core topics (relevant to students of all engineering disciplines) as well as discipline-specific optional topics. These core and optional topic sets were determined by a survey and faculty interviews.

Two organizational approaches to the introductory course are: (1) traditional (metals first)—treatment of structures/properties/processing /applications by material type, and (2) integrated—discussion of each of the material types according to their structures, properties, processing techniques, and applications. The pros and cons of each were presented.

Generating student interest and providing relevance to the subject matter is, to a large degree, the responsibility of the instructor. In this regard, among other things, case studies and reverse engineering examples are effective tools.

Several software packages were presented that contain visualizations, simulations, and tutorials.

And, finally, it was noted that the introductory course may be used as recruiting mechanism for both undergraduate and graduate programs.