

Designing and Implementing a Materials Science and Engineering Program with Limited Resources

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Boise State University (BSU) is located in Boise, Idaho, the state capital, the largest metropolitan area in Idaho, one of the fastest growing high-tech cities in the U.S., and home of Micron Technology, SCP Global Technologies, HP Printer Division, and other high tech companies. The state recognized a need for an university program to educate engineers in Boise and in 1995, it authorized BSU to offer a Bachelor of Science degree in Civil Engineering, Electrical & Computer Engineering, and Mechanical Engineering. The three programs earned ABET accreditation in 1998. In 2000, a Masters of Science graduate program was added to allow students to earn an M.S. degree in the three engineering disciplines. Boise State University is the largest university in Idaho with approximately 17,000 students currently enrolled. Over 600 students are enrolled in the undergraduate engineering program and over 35 in the graduate program.

With the creation of the graduate program and in response to recommendations from local industry, the College of Engineering recognized the need for a emphasis in Materials Science & Engineering (MS&E). The intent of the program is to balance the needs of local industry while still offering an education in the fundamentals of materials science. All three of the MS&E faculty members have multiple years of industrial experience in manufacturing or service oriented sectors as well as R&D labs. We are committed to making the course work convenient for students working in industry as well as directly applicable to their current positions. We are striving to do this for a very diverse community, from the mechanical engineer working for Albertson's to the R&D engineer working on the next generation of memory chips for Micron. By focusing on the fundamentals and bringing in case studies from different technological fields and with a focus on projects and research papers as an essential part of the course work, we try to meet these diverse goals.

The MS&E program is not a separate department but rather a coordinated effort between the three engineering departments and the Physics, Chemistry, and Geoscience departments. The MS&E program is constructed as an emphasis area in one of the other ABET accredited departments rather than a separate stand-alone program. We have created a curriculum that teaches the fundamentals of MS&E in just three or four courses. Students with an interest in learning more in a particular area are encouraged to take additional courses. The civil engineering department is currently re-evaluating their curriculum and may elect to offer a materials science emphasis in the future.

The program has an inherent interdisciplinary nature. It is being developed with all three departments in the college of engineering and with active involvement from Physics, Chemistry and Geophysics. Chemistry will be revamping their curriculum in Fall 2001 and offering a Materials Science emphasis based on the core courses developed in Engineering. A survey course in Materials Characterization with working engineers as its primary audience will be cross listed and team taught with Physics and Chemistry.

The four fundamental courses in MS&E for Mechanical Engineering students are: Introduction to Materials Science & Engineering, Thermodynamics of Materials, Physical Properties of Materials, and Mechanical Properties of Materials. The introductory course is required in the mechanical engineering curriculum, and the Thermodynamics course is one option of the required “depth” courses in thermodynamics, i.e., it is a required elective. The latter two courses can be taken as technical electives in the ME program. These four courses contain the condensed information in a typical 10 to 12 course physical metallurgy curriculum. In our program each course combines the elements of two or three traditional courses. For example, the BSU Thermodynamics of Materials course has elements from both Thermodynamics and from Reaction Kinetics courses. Our Mechanical Properties course includes elements from Physical Metallurgy, Fracture and Fatigue, and Materials Selection courses. Of course, some material has to go to make room for the new material. In the Thermo course, we elected to de-emphasize phase diagrams to make room for Kinetics.

The three fundamental courses in MS&E for Electrical Engineering students are: Introduction to Materials Science & Engineering, Physical Properties of Materials, and Electrical, Optical, and Magnetic Properties of Materials. Currently, all three of these courses must be taken as electives in the Electrical Engineering curriculum. The Electrical Engineering department has initiated a modification of their curriculum to require the Introduction to Materials Science & Engineering for most of their students. Undergraduate students are strongly encourage to take additional courses in solid state physics.

The “conventional” ABET criteria¹ listed specific skill sets required for Materials Science & Engineering that included thermodynamics, mass & energy balances, transport phenomena and “a significant portion” of production, processing, behavior and selection. Although the ABET 2000 criteria² does not have a list specific skills, it does require an “integrated understanding” of structure, properties, processing, and performance. As an emphasis area of an engineering program, the MS&E program concentrates on fulfilling the understanding of the four major elements (structure, properties, processing, and performance) listed in the ABET criteria while relying on the parent departments to fulfill the ABET Criterion 3 (“a through k”).

During the design phase of any course, the fundamental issues are what instructional process should be used and what content should be taught. Content is governed by ABET, industry, and student needs while the instructional process (style and structure) normally follows from pedagogical theory and practice. We used guidelines from the Society of Manufacturing Engineers (SME)³ and the ABET 2000 Engineering Criteria as the guidelines for the needs of

industry. The authors have over 20 years combined industrial experience. During the process of initial course development, each of the authors used their industrial experience in product development, manufacturing support, and process engineering to determine which topics should be emphasized and which could be de-emphasized. We talked to people in our local industries and to our Advisory Board for specific input and we talked to professors at regional universities to understand what knowledge they wanted our students to have.

Boise State University operates on a semester basis and with only the four courses mentioned above, the topics covered in each have to be carefully selected to cover the field of Materials Science & Engineering. We used a well defined system⁴ of instructional planning for each of the courses so that each of the important topics are presented to the students. We used a formal approach for instructional design that included: Determining the instructional goals, Analyzing the goals, Writing performance objectives and Developing assessment instruments.

ABET 2000 requires an assessment of what the students have learned rather than merely a list of the topics that has been covered. The use of written learning objectives focuses⁵ both the teacher and the student on what should be learned and how it will be tested. Additionally, the time and effort to develop and review objectives before teaching the class highlights any gaps and deficiencies in the curriculum. “When clearly defined goals are lacking, it is impossible to evaluate a course or program efficiently, and there is no sound basis for selecting appropriate materials, content, or instructional methods.”⁶ In line with the concept of “continuous improvement” we intend to formally meet and review the objectives, strengths, and weaknesses of each course to assure that each course remains integrated and relevant.

While developing the learning objectives for each course we referred to Bloom’s Taxonomy of Cognitive Domain⁷ to insure that we were teaching at an appropriate level. While it is necessary and desirable to teach the introductory courses using the lower three levels of the taxonomy, the upper division courses are taught using the higher levels of the taxonomy.

Table 1. Bloom’s Taxonomy of Cognitive Domain

1.	Knowledge	(Remembering)
2.	Comprehension	(Understanding)
3.	Application	(Using)
4.	Analysis	(Use component parts)
5.	Synthesis	(Build new application)
6.	Evaluation	(Conscious Value Judgements)

To facilitate teaching each course at the appropriate level, we consciously designed lectures, homework, projects and exams with Bloom’s taxonomy in mind. Introductory courses typically emphasize the first three levels but by use of projects and carefully designed assignments the students get experience in the upper three levels.

We recognized, as others⁸ have, that it is desirable to teach few topics well rather than many

topics poorly. We wanted to provide a cohesive program that built synergy between courses and taught the fundamentals of Materials Science & Engineering in a limited number of courses. We discussed the content of each course and analyzed it to determine which topics should be kept and taught well and which topics could be deleted from the traditional syllabus. An outcome based learning objective was written for each topic (~30 per course). Learning objectives⁹ have the following characteristics: they describe, in measurable terms, what the student will be capable of doing, they describe how the competence will be measured, and they describe what level of proficiency is required and how deficiencies will be addressed.

The following selection of objectives from the Introduction to Materials Science & Engineering course demonstrate the level of detail we used in writing the objectives for each course.

Course Objectives

ME 240- Materials Science & Engineering

All hourly tests will be open book and closed notes. The questions will ask for short, written answers.

Structure & Properties

1. Given a periodic table of the elements, the student will be able to identify the simple metals, transition metals, noble metals, semi-metals, and non-metal elements. By means of the electronic configuration, they will be able to explain why any element should be in one of the categories listed above and why elements in series should have similar chemical properties.
2. The student will be able to interpret micrographs to determine grain size, second phases, and morphologies. The student will also be able to define crystal and amorphous structures and explain how and why the structure affects the mechanical properties.
3. The student will know how to draw the unit cells for FCC and BCC structures and how to determine the Miller indices for 100, 110, and 111 directions and planes in the unit cell.
4. The student will be able to explain plastic deformation, elasticity, and stiffness (Young's modulus) using microscopic (atomistic) models. The student will be able to explain dislocation motion in both BCC and FCC metals and predict the relative ductility and stress-strain behavior of each structure.
5. The student will be able to list at least 4 of the 5 strengthening mechanisms and be able to predict which mechanism is dominant in a given alloy given its chemistry and thermomechanical history.
6. The student will be able to list the three types of bonding and list at least two specific materials that exhibit each type, explaining what characteristics of the material are

derived from the type of bonding. By using differences in electronegativity, the bonding type should be predicted.

7. The student will be able to compare the microstructure and bonding of metal, ceramic, and polymer materials and from this, describe why the different materials have different properties.
8. The student will be able to define and calculate stress and strain and be able to determine the yield stress, tensile stress, Young's Modulus, and elongation to fracture from a stress-strain diagram. The student will be able to relate hardness to strength and list 3 common techniques for measuring hardness.

The full list of objectives for Introduction to Materials Science & Engineering, Thermodynamics of Materials, and Mechanical Properties of Materials can be found at <http://coen.boisestate.edu/dbunnell>

Starting from ground zero without an established degree has allowed us to reconsider the essential material and exactly how to present it. Very few bureaucratic barriers have been placed in our way and we have been able to put together the core of the program in less than one semester. We are also committed to continuous improvement and will reassess on at least a yearly basis, if not every semester whether or not we are serving the need of our constituents.

Our belief is that we teach the fundamentals of Materials Science & Engineering in 3 or 4 courses and give the undergraduate students a solid background that will serve them in industry or graduate school. The students can achieve a significant understanding of MS&E within the current programs (CE, EE, and ME) by using their technical electives. The program attempts to teach the fundamental elements of MS&E with extremely limited resources by focusing on just the critical topics and minimizing superfluous topics. We recognize that high technology industry expects to teach their new employees the specific and current Materials Science & Engineering knowledge unique to their industry and the greatest service we can do to both our students and their employers is to offer a sound curriculum in MS&E fundamentals.

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David E. Bunnell is an Assistant Professor of Mechanical Engineering at Boise State University. Dr. Bunnell is a registered Professional Engineer (Metallurgy) in Idaho. Prior to returning to graduate school he worked for over thirteen years as a process engineer, research engineer, and metallurgist in Colorado and Texas. Dr. Bunnell received a B.S. degree in Chemical and Petroleum Refining Engineering from the Colorado School of Mines in 1978, a M.S. degree in Metallurgical Engineering from the Colorado School of Mines in 1986, and a Ph.D. from The University of Texas at Austin in 1995.

Amy Moll

Amy J. Moll is an Assistant Professor in Mechanical Engineering at Boise State University. She joined the faculty in

August, 2000. Dr. Moll received a B.S. degree in Ceramic Engineering from University of Illinois, Urbana in 1987. Her M.S. and Ph.D. degrees are in Materials Science and Engineering from University of California at Berkeley in 1992 and 1994. Following graduate school, Dr. Moll worked for Hewlett Packard in San Jose, CA and in Colorado Springs, CO. She was an Adjunct Professor at San Jose State University and has been involved in several conferences and workshops on Materials Science and Engineering education.

William Knowlton

William B. Knowlton is an Assistant Professor in Electrical Engineering at Boise State University. Prior to joining the faculty, Dr. Knowlton worked for Insight Analytical Labs in Colorado Springs, CO and Hewlett Packard Laboratory in Palo Alto, CA. His research interests are in reliability physics and materials characterization of semiconductor materials. Dr. Knowlton received his B.S in 1992., M.S. in 1995, and Ph.D. in 1998, in Materials Science and Engineering from the University of California at Berkeley.

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