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AN UNDERGRADUATE CAPSTONE SUBJECT IN DESIGN AND PROCESSING

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ABSTRACT

The curriculum in Materials Science and Engineering (MSE) is extremely broad, as the field encompasses a very large range of both scientific and engineering concepts. The undergraduate curriculum emphasizes the scientific fundamentals underlying the field, as is true of most university courses. However, both students and faculty in the MIT MSE department have felt recently that the curriculum may have become too highly oriented toward science and research, and have worked to increase the number and quality of topics oriented toward design, processing, and real-life practical applications. The senior-level capstone Materials Processing Laboratory (MIT Subject 3.082) is a notable example of this, in which student teams conceive, design and defend the fabrication of a device such as a skateboard, a luminescent display, or a magnetohydrodynamic drive. Many projects involve designing with materials, much like conventional engineering design projects but usually using materials that must be processed from basic starting materials as part of the construction. Other projects involve performing design of the material, manipulating the material through its processing to tailor and optimize its properties for the application at hand.

Keywords: *Engineering, curriculum, materials, design, processing, laboratory*

INTRODUCTION

As its name implies, the 3.082 Materials Processing Laboratory involves working with such processing operations as investment casting of metals, injection molding of polymers, and sintering of ceramics. After the heavy dose of abstraction and theory in the lecture part of the DMSE curriculum, many students have found this hands-on experience with materials to be very fun stuff - several have said that 3.082 was their favorite DMSE subject. The lab is more than operating processing equipment, however. It is intended also to emulate professional practice in materials engineering project management, with aspects of design, analysis, teamwork, literature and patent searching, web creation and oral presentation, and more. (See (1-5) for background on the MIT MSE curriculum revisions leading up to the capstone subject.)

The laboratory has a number of goals: The projects should be fun, and give students a chance to feel the excitement inherent in our field. The laboratory should help solidify the theoretical topics taught in the DMSE lecture curriculum, by reducing them to practice. The projects should involve students in important topics that cannot find room in the rest of the curriculum, such as design, statistics, electronics, machine shop operations, and techniques to promote and justify technical projects. The projects should help develop effective teamwork, and highlight the problems that can arise in team efforts.

PROJECT SELECTION

The students are free to develop projects as they choose, with the instructional staff acting more as coaches and resource persons than as lecturers. The students are given only broad guidance on project selection, to include:

- The project has to live within constraints of available time and resources. Teams can seek resources from anywhere within or outside the Institute, not being limited to the laboratory facilities and staff assigned explicitly to the Laboratory.
- The project ideally treats a wide variety of materials: metals, ceramics, and polymers.
- The project must have a principal processing method – injection molding, investment casting, sintering, etc. – that will be exercised in depth. Auxiliary processing methods are very desirable.
- The project should employ a wide variety of analytical methods and concepts in MSE – all four corners of the processing-structure-property-performance tetrahedron should be present, and treated at a high professional level.
- All teams typically employ modern design and analysis tools such as CAD, FEA, web reporting, and data acquisition/reduction software in managing their projects.
- The project should build on the existing patent and journal literature in MSE.
- Many projects have emulated a startup venture, with market and cost analyses being a natural part of the reporting. This approach works well, but projects with more of a research orientation are also acceptable.

The projects developed by students during the Spring 2002 term are fairly typical:
- Processing and design of magnetic shape memory alloys for vibration damping.
- Alternatives for heated gloves: phase-change materials, electrical resistance heating, exothermic chemical reaction.
- Foamed electrodes for nickel metal hydride batteries.
- Polymer scaffolds for bone ingrowth on a titanium femoral implant.

MIT students are very research-oriented, and tend to propose projects rather beyond the state of the art. This is admirable, but often leads to projects that are difficult to complete in a 13-week term. One of the instructors' principal roles is to moderate this enthusiasm somewhat, to keep the projects within reasonable bounds without suppressing their enthusiasm for exploration. Even so, the students often learn the hard realities of practice as the term comes to an end. Perhaps this is a useful function of a university education.

SUBJECT CONTENT – THE ABET VIEW

Probably all engineering educators are familiar – sometimes painfully familiar – with the current procedures used by the Accreditation Board for Engineering and Technology (ABET). Materials Science departments often have some difficulty with ABET's requirements for engineering design, since MSE curricula are usually weighted so strongly to science content. This has been true at MIT as well, and 3.082 was developed partly with ABET in mind. (In our Fall 2001 ABET review, 3.082 was an important factor in the Department's successful evaluation.) Given its wide use in the engineering education community, the ABET criteria are a useful means of outlining the curricular content of 3.082. Below we repeat the well-known ABET "a-k" criteria, listing outcomes expected of modern engineering curricula, and twenty-five specific activities within 3.082, grouped within five "Instructional Objectives" aimed at meeting these criteria. A matrix is then used to assess the correlation or the various activities with the ABET criteria.

ABET criteria (a – k): an engineering graduate should have

- ability to apply knowledge of mathematics, science, and engineering
- ability to design and conduct experiments, as well as to analyze and interpret data
- ability to design a system, component, or process to meet desired needs
- ability to an function on multi-disciplinary teams
- ability to identify, formulate, and solve engineering problems
- understanding of professional and ethical responsibility
- ability to communicate effectively
- the broad education necessary to understand the impact of engineering solutions in a global and societal context
- recognition of the need for, and an ability to engage in life-long learning
- knowledge of contemporary issues
- ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

The statement of activities and outcomes for 3.082, and their correlation with the above ABET criteria, are listed below. These were been developed by the 3.082 instructional staff (usually four faculty and technical instructors) and submitted both to the students and the Departmental Undergraduate Committee for comment.

3.082 activities

Instructional Objective 1: Develop understanding and experience in materials engineering design.

1. Work in a student team to design a prototype structure or device employing advanced engineering materials.
2. Develop a project management scheme for the materials processing and assembly of the prototype.
3. Explain and justify the design to laboratory instructors and other student teams.
4. Use electronic and conventional means to survey literature and patents relevant to the design, and use these in optimizing the design.
5. Develop a business plan and financial analysis to explore putting the design into commercial production.
6. Develop expertise in computer-aided drafting methods, and generate engineering drawings that can be displayed on the web and in poster format.

Instructional Objective 2: Develop practical understanding and hands-on experience in methods of materials processing.

7. Carry out familiarization trials of processing methods relevant to the team's design, such as lost-wax casting for structural metallic components and sintering of electrically active ceramics for sensors.
8. Develop safety plans for the processes involved in the team project along with the documentation required by OSHA and other cognizant authorities.
9. Locate, purchase, and qualify materials needed in the project.
10. Purchase or fabricate tooling and other hardware needed for the materials' processing.
11. Develop sufficient expertise in machine-shop operations to fabricate needed tooling and perform component-finishing operations.
12. Fabricate components needed in the design, and subject them to appropriate quality assurance testing.

Instructional Objective 3: Review and solidify academic topics by reducing them to practice in the design project. These topics will include both those taught in the DMSE lecture curriculum, and others that must be developed through self-study for the project's needs.

13. Complete appropriate stress analysis, circuit logic, and thermodynamic studies relevant to the design and its expected performance.
14. Complete appropriate theoretical analyses of the fluid flow, heat transfer, chemical reactions and other phenomena controlling the processing of the components.
15. Develop sufficient expertise in statistical analysis and software to generate parametric design experiments as appropriate, and to analyze results of performance tests. Several past projects have employed computer-driven statistical design of experiments, although time constraints prevent this from being a requirement for all projects.

Instructional Objective 4: Improve techniques in communication of technical subjects.

16. Develop web-based documentation to explain and promote the project's goals, underlying engineering principles, processing methods, analytical techniques, progress and final results.
17. Prepare a hallway display-case presentation of the project's salient aspects.
18. Participate in weekly oral presentations of the project's progress, using appropriate and effective speaking techniques and visual aids.

Instructional Objective 5: Develop effective teamwork, and highlight the problems that can arise in team efforts.

19. Listen to all team members' ideas during design process and experiment planning.
20. Identify teamwork problems and address them with team members or instructor.
21. Create plan to share work with team members.
22. Demonstrate ability to implement plan for sharing work with team members.
23. Be able to contribute clear and concise design ideas during class discussions.
24. Create clear and concise oral presentations of preliminary and final designs.
25. Demonstrate ability to incorporate peer and instructor feedback in order to improve design and fabricated items.

Correlation of activities (1-25) with ABET criteria (a-k) : H- high; M-moderate

	a	b	c	d	e	f	g	h	i	j	k
1	H	H	H	H	H	M	H	H		M	H
2	H		H	H	H		H				H
3	M						H				
4			H	H	H	M		M	H	M	H
5	M		H				M	H		H	H
6		H	H	M	H				M		H
7		H	H	H	H		M				H
8		H	H		H	H	H	H	M	H	H
9		M	M	M	H						H
10	M	H	H	H	H		M				H
11		H							M		H
12	H	H	H	H	H		M				H
13	H	H	H	M					M		H
14	H	H	H	M					M		H
15	H	H	H	M					M		H
16				H			H		M		M
17				H			H				M
18				H			H				M
19				H			H				
20				H			H				
21				H			M				
22				H			H				
23	M			H			H				M
24	M			H			H				M
25				M			M				

COMMUNICATION SKILLS – WEB DOCUMENTATION

MIT has a somewhat unusual approach to writing and other communication instruction: subjects in writing are not required, but students do have a requirement to demonstrate communication competence within the context of their regular undergraduate curriculum. This "Communications Requirement" is satisfied in two phases, the first in general writing and administered by the School of Humanities, and the second in technical expository and administered by the student's major department. DMSE students satisfy the second-phase technical communication requirement in the Department's two required laboratory subjects, 3.081 Materials Structure Laboratory and 3.082 Materials Processing Laboratory. The Materials Structure Laboratory emphasizes conventional engineering report writing, while in recent years 3.082 has emphasized various forms of electronic communication and oral reporting. Preparation and delivery of technical reports by PowerPoint and web technology has become standard professional practice, and DMSE seeks to provide experience in this job skill via 3.082.

Each project team develops a web site containing the project's goals, background, results, conclusions, etc.; this site[6] takes the place of the usual written report. Each team member is individually responsible for one of the major web pages (background, design, materials, processing). At the time of the final presentation at the end of the term, the team presents a hallway display of their project that becomes a long-term part of the hallways around the Department.

The web site also contains a link to the team's "electronic laboratory notebook," which is kept current as the term progresses. The notebook contains a concise but thorough description of each day's results and plans, along with data analyses and scanned-in pictures and graphs of important results. The notebook also contains safety-related issues, such as MSDS's for each material used and safety protocols for each experimental procedure carried out by the team.

The online laboratory notebook as presently implemented is not able to preserve confidentiality or to protect proprietary information. This is in keeping with MIT's policy on openness of academic work, but would not be typical of procedures followed in many industrial firms. In future terms, 3.082 might experiment with some of the commercial notebook packages that are now available, and that can replicate industrial practice more realistically.

CONCLUSIONS

The Materials Processing Laboratory has become a very popular part of the MIT MSE curriculum, and the faculty feel it is very useful in helping balance the more theoretical aspects of our educational package. The Department is now engaged in a very substantial effort aimed at revising our undergraduate curriculum. It is expected that the practical and design-oriented features now in 3.082 will be expanded and placed throughout the curriculum rather than being concentrated in one laboratory subject.

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