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Engineering Project Laboratory Modules for an Introduction to Materials Course

Abstract

The final results of curriculum development under an NSF, CCLI-EMD sponsored project, "Development of Project-Based Introductory to Materials Engineering Modules" (DUE # #0341633) is discussed. A multi-university team of faculty developed five lecture and three laboratory modules for use in Introductory to Materials courses. This course is required by most engineering programs in the U.S., with an annual enrollment of 50,000 students.[1] This freshman/ sophomore class is an ideal place to excite students about their engineering majors and expose them to real world engineering problems. PRIME Modules, Project Based Resources for Introduction to Materials Engineering, utilize modern materials science and engineering technologies and proven education methodologies of active learning and open ended projects.

Five classroom modules have been developed and utilized in an Introduction to Materials classes. There is a non-volatile memory module that teaches electronic and magnetic properties in the context of non-volatile memory (such as Flash and M-RAM). In another module, students learn about solid oxide fuel cells and the ceramic nanomaterials used to fabricate them. While studying this emerging application, students learn about ceramics, defects, and phase diagrams. A third module exposes students to fiber reinforced plastics used for civil infrastructure such as bridges. The fundamental content covered includes mechanical properties, diffusion, polymers, and composites. There is a biomaterials module on stents that teaches students about crystallography and mechanical properties of metals. Lastly, a sports materials module teaches the mechanical properties of polymers and composites while exploring more about skis and snowboards. Each classroom module contains background resources for faculty, lecture notes, active in class exercises, homework problems, and a team project. The project is designed to be an open ended research project that engages the student more deeply in the modern technology covered by the module. Detailed information on the content of these modules is published elsewhere.[2,3] Further assessment of the modules is included in this paper.

Three laboratory modules have been developed that teach the concepts covered in a traditional introduction to materials lab in the context of an engineering scenario designed to illustrate the role a materials engineer plays in industry. The fundamental concepts of crystal structure, defects, mechanical testing, and corrosion are taught in a project where students select a metal for an off-shore oil rig. In another module, students engage in thermal processing, mechanical testing, metallography, and failure analysis in an open ended project to investigate why a steel component failed in a mock application. Students learn about polymer processing and the mechanical properties of composites in a project where they design and fabricate a composite for a hybrid car panel based on optimizing strength and cost. Each lab module contains learning objectives, background resources for faculty, lecture notes, small labs to learn theory and equipment operation, an open ended lab project, and grading rubrics for the writing assignments. The each lab module contains a significant writing assignment that is geared to actually teach writing

to the student and to provide a format and context of writing that will be relevant to their future engineering careers.

Background

Throughout history, major advancements in technology have been marked by materials. Each new technical innovation has required discoveries in materials to surmount barriers and limitations. This has led to an overlap between materials science and almost every other engineering field. Electrical engineers use materials science and engineering to produce computer chips, lasers, and superconductors. Structural materials such as concretes for roads and metals for buildings and bridges are crucial to civil engineers. Mechanical engineers must consider the strength and long term reliability of the materials used in their designs. Light weight, strong materials are continuously researched and tested by aerospace engineers. Biomedical engineers investigate alternative materials for transplants, artificial limbs, and surgical tools.

For this reason, most engineering programs require their students to take an introductory materials class. This includes community colleges with engineering transfer programs. In the U.S. alone, the "Introduction to Materials" course enrolls over 50,000 students a year.[1] The primary goal of the class is to provide a foundation in materials science and engineering that the students can build upon in their major classes and future careers. The curriculum and lab content for the traditional "Introduction to Materials" course taught at San Jose State University is given in Table 1. Researching the equivalent course at other institutions showed that most courses cover the same material in a similar format. In a search of online syllabi, the first twenty syllabi investigated all covered at least 80% of the lecture topics in Table 1. The standard texts for the course cover the topics in Table 1.[4,5] This is significant in that the modules developed for use at San Jose State University could have widespread applicability because they are used along with traditional texts and cover the same curriculum as in most Introduction to Materials courses.

Table 1: Outline for San Jose State University's traditional "Introduction to Materials" course.

Lecture Topics	Lab Topics
Atomic Structure & Bonding	Crystal Models & Defects
Crystal Structure	Hardness Test
Imperfections	Fracture Test
Diffusion	Tensile Test
Mechanical Properties	Cold Working
Strengthening Mechanisms	Pb/Sn Phase Diagram
Phase Diagrams	Tempering of Steel
Electrical & Magnetic Properties	Ductile to Brittle Transitions
Ceramics	Corrosion
Polymers	Polymer/ Composites
Composites	Electrical & Magnetic Properties

Project Based Resources for Introduction to Materials Engineering (PRIME) modules have been developed to teach the fundamental principles covered in a typical introductory materials course within the context of modern engineering technologies. The same fundamental principles of materials science and engineering that are typically delivered in a traditional lecture model of an Introduction to Materials course are taught. However, the fundamental topics are arranged in project based modules that focus on a modern technology.

The use of relevant, industry examples expose freshman and sophomores to realistic engineering situations. The modules accurately inform and excite students about recent technological advances. By tying the fundamental material to technologies, students obtain a "bigger picture" view of the field. Placing the "Introduction to Materials" curriculum in a framework where the students can see its relevance to their interests and the world around them should increase their understanding and retention of the material.[6] Balancing the concrete and abstract content should cater to different learning styles, especially benefiting global learners who suffer in traditional forms of the class that do not emphasize the "bigger picture".[7] Cabral *et al.* showed that placing the fundamental material within the context of an applied situation increases students motivation to learn.[8] Each lecture module will have an open ended project that student teams work on throughout the course of the module. The project is integrated into each module in order to increase student ownership of their learning and to deepen students' understanding between the connection of the fundamentals they are learning with real world engineering applications.[9] The fundamental material appears in multiple modules. This allows students to revisit the material over the course of the semester and build upon what they learned earlier to obtain a deeper understanding.

The "Introduction to Materials" class is typically taught at the freshmen or sophomore level. Therefore, changes made in the course have the possibility not only to impact student learning of the material but also to improve retention in engineering programs in general. A survey on retention of engineering students at Arizona State University found that students cited "interesting work" and "many job opportunities" as among two of the top three reasons (the other being salary) for choosing an engineering major.[10] Surveys of freshmen and sophomores who left engineering found that the most important reason cited for women and second most important for men was that the "reason for choosing the major was found inappropriate". In other words, a significant number of students were not retained because they no longer felt engineering offered interesting work or many job opportunities. Thus, retention of engineering students may be improved by placing the freshman and sophomore curriculum more in the context of true engineering where they can see these opportunities. Efforts across the nation to enhance the engineering experience in freshmen courses by adding design and/or project based components are a reflection of this effort.[11, 12] Assessment has shown that introducing design and project based learning to early engineering and technology students has improved retention.[13, 14] A similar effort is called for in the introduction to materials course, where examples of real world engineering could provide an improvement in retention.

This issue of retention is a national concern as enrollments and undergraduate engineering degrees are down across all demographic categories.[15] Therefore, if shown to be effective retention tools, these modules have the potential to have a broad, national impact on this critical problem. While the use of these modules to enhance retention will benefit all students, an even more significant impact could be made on the retention of female students and under-represented minorities as the degree completion rates of these students are significantly less than their white male counterparts.[10, 16, 17]

Lecture Modules

Five classroom modules have been developed and utilized in Introduction to Materials classes. The modules teach the same fundamental concepts as in a traditional Introduction to Materials course. The content, however, is focused around an engineering application (technology). Table 2 lists the lecture modules developed along with the fundamental objectives they teach. These are classroom based modules that can be utilized within the framework of a traditional lecture only class. Each classroom module contains background resources for faculty, lecture notes, active in class exercises, homework problems, and a team project. The project is designed to be an open ended research project that engages the student more deeply in the modern technology covered by the module.

Table 2: PRIME Modules developed to date to teach fundamental materials principles in the context of modern materials technologies.

Module Technology	Fundamental Topics Covered
Biomaterials: Self-expanding stents made from shape memory alloys	Crystal structure of metals Defects Introduction to phase change & phase diagrams Mechanical properties of metals Processing & strengthening mechanisms in metals
Nanomaterials: Ceramic nanomaterials for solid oxide fuel cells	Crystal structure of ceramics Properties of ceramics Ionic defects Advanced phase diagrams Introduction to diffusion
Electronic & Magnetic Materials: Non-volatile memory devices for portable electronics	Atomic bonding and electron configurations Band structures of metals, semiconductors, and insulators Conductivity of metals and semiconductors Capacitance Introduction to transistor operation Magnetic moment, magnetic domains Hysteresis loops Solenoids
Composites: Fiber reinforced composites for civil infrastructure	Comparison of stress strain diagrams of all materials Polymer processing and properties Mechanical properties of composites Advanced diffusion
Sports Materials: Polymers and composites used in snow boards	Comparison of stress strain diagrams of all materials Polymer processing and properties Mechanical properties of composites

Assessment of Lecture Modules

Student opinions of the modules was collected through surveys and is reported in detail elsewhere.[3] In summary, the general response from students is that they enjoy the modules and they feel they are an effective way of learning the material. Most of the students (39%) enjoyed the Introduction to Materials course a lot or somewhat more than their other engineering courses. The majority of students (69%) self-reported learning a lot or somewhat more in the Introduction to Materials course relative to their other engineering courses. The written feedback on student evaluations indicates that, in general, students value the use of the technologies, the organized PowerPoint slides, active in class exercises for each class, and the team projects. Students appreciated the fact that the fundamental material is repeated in the modules. Negative comments indicate some students are bothered by not following the textbook order and having to learn extra material not covered in the text.

The Materials Concept Inventory Quiz (MCI) was administered to assess the learning from a quantitative standpoint. The MCI is a multiple choice test designed to gauge student understanding of fundamental materials concepts.[18] The test was administered anonymously to students at San Jose State University, a similar public institution in a different state, and a California community college in courses from Fall 2005 through Fall 2007. The test was administered at the beginning and end of the semester to all sections. Some students were in a PRIME formatted course, meaning they used the PRIME modules throughout the entire semester. Some students were in a “mixed” course, meaning they used 1-2 of the PRIME modules and the rest of the course was taught in a traditional manner. The remaining students were in a traditional version of the course. The results are given in Table 3. The scores are out of a possible 30. The relatively low final scores reflect that the questions on the MCI do not directly relate to the material taught in the course. The low exit scores from these introduction to materials courses are similar to those reported in the literature.[19, 20] Note, in the Fall 2005 pre-test, it was not recorded which lecture section the student was in. However, comparing to the pre-test data for Spring 2006, there was essentially no variation in the lecture sections at the start. The variation in results seen from the same instructor semester to semester (Instructor A with the PRIME modules) and between different instructors is comparable. This data indicates that, within the scope of concepts covered by the MCI, the PRIME module format successfully teaches the same level of fundamental concepts as a traditional format.

Table 3: Results of pre-tests and post-tests for the Materials Concept Inventory Quiz. Scores are out of a possible 30. The mode indicates "Prime" where the whole semester was taught in the module format, "Mixed" where 1-2 modules were used and the rest of the semester was taught in a traditional format, and "Trad" where the whole semester was taught in a traditional format. The universities reported here are San Jose State University (SJSU), another similar public institution in a different state, and a California community college. The Instructor is indicted by a letter to compare the same and different instructors. *The Fa05 pre-test data did not indicate whether the student was in the PRIME or traditional class.

Mode	Univ.	Instr.	Year	Pre-Test Score			Post-Test Score			Gain
				#	Avg	St Dev	#	Avg	St Dev	
Prime	SJSU	A	Fa 05	70*	9.65	3.44	44	12.20	4.16	2.55
Prime	SJSU	A	Sp 06	69	9.54	3.18	61	11.69	3.39	2.15
Prime	SJSU	A&B	Sp 07	90	10.4	3.59	87	12.26	3.94	1.86
Mixed	Different state school	C	Fa 06	18	10.22	3.22	16	13.75	3.64	3.53
Mixed	CA CC	D	Fa 07	18	8.39	3.11	13	9.69	3.20	1.3
Trad.	SJSU	E	Fa 05	70*	9.65	3.44	36	11.78	4.31	2.13
Trad.	SJSU	F	Sp 06	60	9.56	3.40	50	12.29	3.37	2.73

The impact of the modules on student's motivation to learn was assessed with the Instructional Materials Motivation Survey (IMMS). This is a 36 item instrument in which students are asked to rate various statements regarding the instruction they have received using a Likert-type response set.[21] This test was administered in Spring 2007 to tow different courses of the same instructor. One course was an introduction to materials course using the PRIME modules with 96 students in two sections. The other course was an introductory electronic materials course taken by predominantly electrical engineering majors with 43 students. Table 4 shows the results of the comparison. The courses were somewhat similar in content and very similar in the structure of the classroom environment in that the same instructor used the same board writing style mixed with active, in-class exercises. The major difference between the two courses was the use of the project based modules in the Introduction to Materials course. The IMMS results show similar (within the standard deviation) results between the two courses. The project based courses shows a slightly higher impact on student motivation, particularly in areas of attention and relevance. The students in the project based course showed a slightly lower rating in confidence and satisfaction.

Table 4: Comparison of IMMS results from an Introduction to Materials course with project based modules and an Introduction to Electronic Materials without a project based component.

IMMS Scores	Introduction to Materials with project based modules		Electronic Materials course without project based component	
	Average	St Dev	Average	St Dev
Total IMMS score	3.11	0.59	3.02	0.53
Attention sub-scale score	3.25	0.64	2.99	0.67
Relevance sub-scale score	3.28	0.61	3.10	0.64
Confidence sub-scale score	3.02	0.70	3.03	0.62
Satisfaction sub-scale score	2.70	0.86	2.97	0.92

Engineering Project Laboratory Modules

The previous laboratory component of San Jose State University's Introduction to Materials class, listed in Table 1, were a series of one week lab experiments. The experiments were very typical to those used in most other Introduction to Materials courses. The laboratory class was redesigned using multi-week modules with an emphasis on realistic engineering projects. The goals of doing so were similar to the re-design of the lecture modules described above. Creating a more open-ended nature to the labs will increase students' ownership of the labs and their motivation to learn. The context of a real world engineering setting will help students see how the fundamental concepts relate to their future careers as engineers. Especially in a service course where most of the majors are not materials engineers, the lab modules are designed to show the students how they will need an understanding of materials in their future careers. The lab modules give the students a clearer image of what an engineer does in industry early in their academic career. These lab modules were built on the framework of the existing one week modules. That is, lab experiments were re-designed to be more open ended and grouped together to show students how multiple concepts work together to solve one engineering problem. The advantage of this is that the modifications made in the laboratory class should be very portable to other institutions with a traditional lab class framework in existence already.

Three, multi-week engineering project laboratory (EPL) modules were developed. Each module contains an engineering based scenario that emphasizes the roles materials engineers have in materials selection, optimization of manufacturing processes, and failure analysis. The modules have a complete set of resources designed to make them easily utilized by new instructors, Figure 1. Each module contains learning objectives, a project description, background information for faculty, lecture notes and overheads, equipment instructions and materials lists, worksheets and mini-lab experiments to guide students through learning the fundamental concepts and equipment, and quizzes. The modules also have components on teaching and assessing writing and oral communication. This includes detailed grading rubrics that have been shown to improve the quality of student writing, reduce faculty grading time, and create more consistent grading between different faculty.[22]

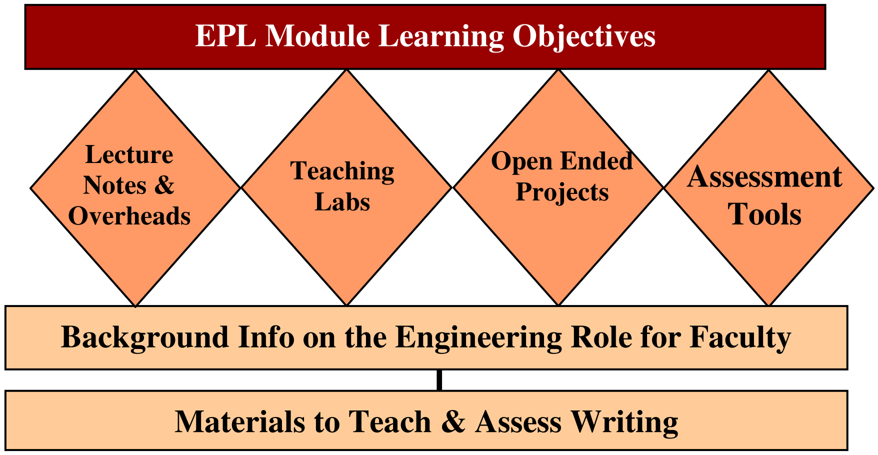

Figure 1: Schematic of the components in each Engineering Project Lab module.

Table 5 lists the modules developed. The fundamental concepts of crystal structure, defects, mechanical testing, and corrosion are taught in a project where students select a metal for an off-shore oil rig. Students study in depth the phases of steel, thermal processing, metallography, and failure analysis in a multi-week project to investigate why a mock steel application failed based on the supposed composition and thermal processing. In another module, students are exposed to polymer processing and the mechanical properties of composites in a project where they design and fabricate a composite for a hybrid car panel based on optimizing for both cost and strength.

Table 5: Engineering project based labs developed for an Introduction to Materials Course

Engineering Project	Fundamental Concepts	Mini-labs
Selection of a metal material for an off-shore oil rig optimizing mechanical and corrosive properties	Crystal structure Miller indices Dislocations, slip planes, and slip directions Stress strain diagrams Mechanical testing Ductile and brittle failures Galvanic series	Build models for crystal structure and planes and directions Tensile test of various metals Charpy impact test at different temperatures Create a Galvanic series Writing worksheets to improve paraphrasing, organization, and editing
Failure analysis of why a steel part failed based on supposed composition and thermal processing	Phase diagrams Lever rule Phases of steel Time - temperature transformations Metallography Microstructure	Tempering of steel Metallography Microscopy
Design of a composite for a hybrid car panel that optimizes mechanical properties and cost	Structure of polymers and composites Casting and polymer processing Mechanical properties of composites	Calculating mechanical properties of composites Casting

The first project is a four week module where the students are consultants hired by an oil company to recommend the metal material from which to build the platform out of. Students need to select a certain metal from a given set of choices based on the mechanical properties, low temperature failure mechanism, and corrosive properties. Students create an engineering memo for the oil company which includes detailed information about the metal's crystal structure, slip systems, and mechanical and corrosive properties. Worksheets are designed to guide the students through learning about crystal structure, Miller indices, slip plans and directions, the Galvanic series, tensile test, and Charpy impact test. Resources for the lab instructors include lecture notes and overheads to teach the fundamental concepts. The module also contains active exercises to teach the students how to paraphrase and not plagiarize, structure an executive summary, and edit their own writing.

In a module focused on the properties and processing of steel, the students are mock consultants hired to determine why a specific steel sample failed. They are given the supposed composition and thermal processing of the piece. They need to design and run experiments on thermal processing, mechanical testing, metallography, and microscopy to understand the connection between thermal processing, microstructure, and mechanical properties in steel. Further emphasis is given in this module on teaching the students how to organize their writing and properly reference other sources. Worksheets guide the students through understanding the phase diagram and microstructure of steel, metallography, and recognizing microstructure in metal samples. The final outcome is an engineering report to the "manufacturer of the steel part" that details the student's findings.

In another module, students are engineers working at a car company who need to choose a composite material for the side panels of a hybrid car. The students have three weeks to design, fabricate, and test the composite material based on optimizing cost and mechanical properties. Students create their own polymer composite dog bone samples learning about casting and the mechanical properties of composites. Worksheets guide students through calculating the mechanical properties of composites based on matrix and filler type and ratio. The final outcome of the project is an engineering memo comparing their theoretical calculations of the mechanical properties with their measured values. The "car company management" evaluate each "employee team's" suggestion to determine who has found the best solution when considering both cost and strength.

Assessment Plan for Laboratory Modules

The laboratory modules have finished the beta testing process and are being utilized in Spring 2007 in the complete form. Assessment of the fundamental concepts are built into the modules including laboratory quizzes, worksheets, individual oral exams, and writing assignments. The oral exams and writing assignments include detailed grading rubrics for the faculty. The analysis of the rubrics from the different laboratory instructors will be assessed to determine if the rubrics were effective in making the grading of the writing easier and more consistent. Surveys will also be utilized to assess both faculty and students' impressions of using with the modules.

Conclusions

Project based modules were developed for use in an Introduction to Materials Engineering course. The modules teach the fundamental concepts of materials science within the context of modern engineering applications. The main goals in integrating the fundamental concepts with advanced technologies is to help students see the connection between what they are learning and real world engineering issues and to motivate them to learn on their own.

Five lecture modules have been developed. Each is designed to take 3-5 weeks of class time. The technologies focused on the in the modules are biomaterials used in self-expanding stents, ceramic nanomaterials for solid oxide fuel cells, non-volatile memory options for portable electronic devices, polymers and composites in skis, and fiber reinforced plastics used in civil infrastructures. Throughout the course of each module, teams work on open-ended projects that help them relate the fundamentals to the technology. The projects are used to increase student ownership and motivation in learning. In addition to the projects, the module development includes background resources for faculty and students on the technology. This allows the modules to be taught by faculty with little or no experience in the technology area. Each class period of the module has learning objectives, a reading assignment with reading review notes, instructor notes and overheads, active in-class exercises, and homework problems related to the technologies.

39% of the students surveyed enjoyed the module format more than their other engineering courses. 69% students self-report learning more than in their other engineering courses. Within the scope of the concepts tested on the Materials Concept Inventory Quiz, students in the module format version of the course learn the fundamental principles at the same level as students in a traditional course. The Instructional Materials Motivation Survey shows the project based course had a slightly higher impact on student motivation in the areas of attention and relevance

Three laboratory modules were developed to expose students to the roles materials engineers play in industry. The modules had open ended projects with industry like scenarios. The fundamental concepts of crystal structure, defects, mechanical testing and corrosion are learned through a project to select a metal for an off-shore oil rig. In another module, students design and carry out experiments on thermal processing of steel and investigate the influence of this processing on the mechanical properties and microstructure. In a third module, students design, fabricate, and test composites for a hybrid car panel. Their designs are based on optimizing both strength and cost.

Each module contains learning objectives, a project description, background information for faculty, lecture notes and overheads, equipment instructions and materials lists, worksheets and mini-lab experiments, quizzes, and detailed grading rubrics to assess the writing. The laboratory modules were developed by re-designing existing one week lab experiences to make them more open ended and connected to a real world engineering scenario. This re-design methodology makes the laboratory modules easily portable to other institutions with an existing traditional course framework.

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