DESIGNING FOR STUDENT SUCCESS: A MATERIALS SCIENCE CASE STUDY

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ABSTRACT

Materials scientists are responsible for innovation in a variety of areas, including manufacturing processes, sustainability, and new product development. To be successful, a materials scientist must understand not only the relevant technology, but also how its implementation is affected by patent law, the economics of manufacturing, and effective communication with the public, other scientists, and engineers. At Massachusetts Institute of Technology, the Materials Project Laboratory course (3.042), prepares students by providing interdisciplinary training focused on real-world challenges. Students solve problems by creating new materials that address specific needs in medicine, construction, consumer goods and other areas; they execute a project from theory to patent and marketing research, culminating in the production and presentation of working materials. Along the way, students write and speak about their plans and progress, communicating on a regular basis with experienced professionals in their field. Because technical work, research, and communications are inextricably intertwined, they gain practice in working as professionals, solving problems not only in the lab but also in teamwork and leadership. Having experienced the challenges of working on complex problems, they complete the course ready to advance knowledge in the development of new materials.

KEYWORDS

Project-based classes, Engineering pedagogy, Materials Science Education, Technical Communications pedagogy, Teamwork and management education

INTRODUCTION

Materials science plays a role in many industries and is crucial to innovation and new product development. From a technical standpoint, materials scientists need a strong background in both science and engineering. Because of the nature of the work, a growing need exists for materials scientists to be qualified as scientists, researchers, and innovators. Moreover, the nature of the projects they work on requires the ability to work in teams, make business plans, and apply critical thinking skills in areas such as marketability, manufacturing costs, and the environmental impact of products. At the Massachusetts Institute of Technology, the Materials Science Project Lab, known by its course number, 3.042, offers students the opportunity to plan and implement projects from inception to completion. This experience allows students to take risks, engaging in experimental projects that break new ground. The possibility of unforeseen problems adds a real-world dimension to the challenge of working in teams and presenting results at key milestones throughout the 14-week development cycle.

During the Fall semester of 2012, the class added a writing component to the existing communication requirement. The implementation of this component was observed and documented, together with existing elements such as material from the Gordon Engineering Leadership program and the traditional laboratory Destruction Day session. Students submitted their evaluative responses to open-ended questions at the end of the semester. This observation and evaluation is part of an ongoing process of continuous improvement, with the goal of equipping 3.042 students to better understand and communicate materials science concepts; adopt professional behaviors and attitudes; employ practices to enhance group productivity and collegiality; and develop innovative materials and processes. Although the goals of 3.042 were not explicitly developed with the CDIO syllabus in mind, the authors believe that the knowledge, behaviors, practices, and innovation encouraged by this course is commensurate with goals described in the CDIO syllabus. [1]

PROJECT-ORIENTED ENGINEERING COURSES AND MATERIALS SCIENCE

Since the mid-1990s, project-oriented engineering courses, also known as senior labs, capstones, and design-oriented classes, have become increasingly common. They are seen as a way to ensure that students learn practical, hands-on skills to complement the theoretical education they receive during their undergraduate years. In addition, as the scope of engineers' professional responsibilities evolve, these courses are increasingly seen as ways to give students experience in the skills needed to work as managers or entrepreneurs, with requirements that include teamwork, communications, and strategic planning. In particular, the need has been identified within the materials science field for graduates that exhibit technical competence and a diverse set of complementary skills. [2]

The Accreditation Board for Engineering and Technology, Inc. (ABET) emphasizes a wide range of objectives and outcomes that stress not only technical competence, but a diverse set of skills that includes working in teams that include specialists from more than one area, understanding professional ethics, and communication. [3] Project-oriented courses teach these skills by presenting them in a context that forces teams to apply critical thinking as problems emerge and reflect on the process used to solve problems. [4]

3.042: COURSE STRUCTURE AND PEDAGOGY

Materials Science Laboratory, known as 3.042, is required of all Materials Science majors at the Massachusetts Institute of Technology. By their senior year, students have fulfilled one of two recommended paths for completing the prerequisites and this course completes their experience. Materials Science Laboratory is offered in both the Fall and Spring semesters, and all seniors are required to take it. Working in teams, students pursue laboratory projects in materials science that include the development of fly ash brick and tile, foamed ceramics, jamming materials, innovative crutch designs, and new designs for heat-conserving blankets.

Interaction Between Lab Work and Lectures

The semester routinely begins with project selection and the formation of teams. In the Fall of 2012, students also filled out a self-analysis survey to identify their level of writing and speaking experience as well as their communications and teamwork goals. Students then had an opportunity to select a topic from the list of available projects. The instructors assigned four teams of four students to work on each project. By the second week of class, students produced a team-written commitment statement, which outlined their learning goals for the semester and the actions they intended to perform in order to reach those goals. The second week of class was also the time when students were introduced to the MIT library system and the resources they would need to do a literature review. In this way, students saw the combination of technical, research and communication instruction from the first days of the class.

Also during the second week of class, a lecture in materials identification and joining was offered, to introduce students to the importance of appropriate materials selection. Laboratory work in the initial weeks of class helped the students understand the nature of the work they will be expected to do and introduces them to the norms of the field. "Destruction Day" required students to break down a project into its various parts to understand how it was made and produce exploded diagrams. This process allowed students to see the practical application of techniques such as machining, milling, welding, and blow molding.

Reviewing their Destruction Day experiences at the end of the term, students' comments were generally positive. They reported an increased understanding of the materials process and of the process for analyzing materials used. Some students also mentioned the process as an opportunity for team building and getting to know the course instructors. Asked for suggestions to improve the experience, students' ideas included placing greater emphasis on gaining practice with the tools they would need to use for their projects and taking apart smaller machines so that teams could put them back together within the allotted time.

Business and Intellectual Property

Students learned about the legal and technical ramifications of patenting. These included the requirements for submitting patents, as well as the rights and responsibilities of patent owners.

As part of the course curriculum, students learned the basics of cost modeling, with the express goal of moving out of the comfort zone of research to understanding how to appropriately identify research problems, the current state of the technology they were investigating, the realities of estimating costs, and the importance of looking ahead to economic changes that might affect the viability and feasibility of a product. Students learned to identify the key costs affecting the success of the project and how to attack problems in costing to ensure that the solutions they devised were both technically and financially innovative. Lectures emphasized the importance for materials scientists to find right metrics to analyze the worth of a given innovation. Training stressed that even when technological success is assumed, cost impacts still need to be considered. As students developed their projects, it was expected that they would understand the value proposition as well as articulating their cost model against industry standards. After the first presentation, students were expected to know and their projects' basic costs, including the Bill of Materials (BOM), Cost of Goods Sold (COGS) and gross margin.

Role of Speaking and Writing

Oral presentations were made to the class and instructional staff at key milestones in the development cycle. They required students to document their accomplishments and decisions made to date. At the same time, the presentations were an opportunity for the technical staff to ask questions and give suggestions. The first presentation happened in Week Three, when each team was required to make an initial design review presentation, which included: project goal and prototype design specs; background, literature review, theory, methods; experimental design considerations; project timeline and Gantt chart; risk assessment and backup plans. This presentation was prepared for an audience of technical managers. During the final design review, students presented a final project goal and prototype design. They summarized progress to date and the main challenges to come. Additionally, the presentation included financial/market analysis as well as a timeline and backup plans. As part of this presentation, students were required to produce an "alpha" prototype of materials.

At the conclusion of the semester, final presentations were given to an audience that included senior materials science faculty and other interested parties. The presentation itself was twenty minutes long, with ten minutes for questions. Students were required not only to present clearly and accurately, but also to be prepared for technical and non-technical questions on any aspect of the project. Presentations were directed at a "senior management" audience, with a clear restatement of the project goal, background and theory, and prototype development path. The description of the target market/financial analysis as well as underlying data used to make the strategic and technical decisions needed to be clear and unambiguous. Where possible, the final presentation also included a demonstration of working materials.

Update presentations were shorter and assumed an audience of peers familiar with project. Students were expected to give a concise, technical report of the details of progress since their last presentation. They justified decisions and the research strategy chosen, supporting these decisions with their own experimental data or previously published data. Update presentations also included an explanation of next steps and contingency plans as well as explanations of changes to the schedule.

All reports were team-written, with the expectation that all team members would contribute to the writing of the report. In project-based classes, writing is often seen to be an "extra" burden for students. Writing assignments for 3.042 were designed to help students get their ideas and plans into written form by requiring them to document the design and development process during the normal course of work. The writing was built into the curriculum as an aid to planning and clarifying ideas. An initial, brief report, due approximately one-third of the way into the semester, required students to articulate the written project design, including project goal and prototype design specifications; experimental design outline and roadmap; the project timeline/Gantt chart; and a budget. The team also wrote a more extensive progress report, due in the middle of the semester, and a final paper that documented the entire project, which is due in the last week of class. The aim of the assignment design was to teach not only the professional conventions but also the habits of documenting the design process and writing cooperatively as a group.

Responding to end-of-term questions on the class in general, students requested more detailed information on presenting data and creating slides. Of the 15 respondents, five spontaneously mentioned "communicating" or "presenting" when asked to summarize what they had learned in 3.042.

Teamwork and Management

In describing the curriculum, many references have been made to the team-based nature of the technical and communications work. The fundamental expectation underlying the design of 3.042 is that students work in teams, taking turns with the responsibility for leadership and decision-making. Three times during the Fall 2012 semester students did anonymous peer reviews and used the results to set and refine their goals for the duration of the project.

In addition, the students received mentoring through the Bernard M. Gordon Leadership Program at MIT. A teaching assistant with expertise in both leadership and materials science accompanied the students in their work throughout the semester. Lectures on entrepreneurship emphasized the importance of assembling a team that included experts in technology, management and business development, and finance. In addition, experienced professionals shared information on long-term success through productive communication with employees at all levels of an organization. Advice such as getting to know quality assurance engineers who might catch a costly mistake before it enters the manufacturing process helped students see beyond the abstract concepts to practical habits of professionalism.

At the end of the term, students were asked about the implementation of the Gordon Engineering Leadership material for the class. Eight respondents were unreservedly positive, with comments such as, "It was nice to have the leadership roles rotate, [as] it eliminates the potential for one person to dictate the project [for] the whole semester." Other respondents qualified their responses with questions about the motivation and competence of fellow students in leadership roles. Two respondents suggested focusing on a just a few leadership traits.

ASSESSMENT AND OUTCOMES

As 3.042 is repeated semester by semester, the curriculum continues to develop in response to instructor experience and student feedback. In the process, the criteria for assessment have become more rigorous. With each successive semester, the products produced by teams are held to higher standards. At final presentation for Fall semester 2012, the audience had access to the materials produced by the students during the semester and asked questions of the team.

This public question and answer session gave students the opportunity to explain materials science concepts to the general public in an encounter that showed the completed project in a general-interest context. In addition, the lab instructors reviewed the quality of the material and whether or not it accurately met the goals established by the student team at the outset of the semester. Written work and oral communication were also evaluated against criteria set forth on the syllabus. The students' basic competence in speaking and report writing has improved, and at the conclusion of the semester the teaching team determined that it is now desirable to hold students to ever-higher standards, such as specificity in discussing theoretical and scientific concepts and greater concision in their writing style.

For Fall semester, 2012, a written survey was administered to students requesting answers to five open-ended questions. In general, responses were positive, with negative comments focusing on the competition engendered when two teams undertake the same project. Reasons given included scarcity of equipment and laboratory resources, with one student reporting, "It was difficult to comment on [the other team's] presentations critically without looking like a jerk."

Overall, students reported satisfaction with the course and with their accomplishments. A few students expressed concern with the amount of time required for course and lab work. In response to questions about the efficacy of peer review, some students reported that, beyond a few positive comments, it was difficult to evaluate peers when things were going well. Students also expressed the desire for more rigorous criticism from the course instructors during presentations and lab conversations. In general, students praised the hands-on aspect of the course, the experience of encountering and overcoming setbacks in lab and in teamwork, and the experience of learning a varied and readily applicable skill set. A typical summary comment was, "I learned how to design a project from literature search to prototype stage and how to present my progress and work."

Materials Science Project Laboratory, known as 3.042, continues to engage and challenge seniors. A writing component was successfully added to 3.042 during the Fall 2012 semester. As the course continues, the aim of the instructors is to continue to raise the standards for laboratory work. In addition, there is a desire to see students apply more critical thinking to the business side of their project plan. In planning communications assignments, attention needs to be paid to training students to communicate to other materials scientists with an appropriate level of depth and rigor. At the same time, as future entrepreneurs and consultants, students will need to communicate the underlying scientific concepts, testing results, and business plans in a way that can be readily understood by the general public and by an audience of managers.

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