Journal of Materials Education Vol. 31 (1-2): 37 - 44 (2009)

CREATING A PROJECT-BASED CURRICULUM IN MATERIALS ENGINEERING

Katherine C. Chen[1], Linda Vanasupa[1], Blair London[1], Trevor Harding[1], Richard Savage[1], William Hughes[1], and Jonathan Stolk[2]

[1] Materials Engineering Department, California Polytechnic State University, San Luis Obispo, CA, USA; [2] Franklin W. Olin College, Needham, Massachusetts, USA

ABSTRACT

For the past two years, the Cal Poly Materials Engineering department has been on an endeavor to create a modern, innovative curriculum to train a more diverse set of materials engineers for the global and complex world of the 21st century. The traditional lecture and laboratory activities have evolved into more open-ended, project-based experiences that help students develop additional skills and contextualize the learning of theories. Different types of projects are embedded throughout the curriculum to achieve particular learning objectives while emphasizing different content. During class time, students are extremely active and the faculty act as coaches and mentors to the students.

This different approach to learning is designed to encourage students to become more independent self-learners, as well as to better integrate concepts with practical experiences. The varied activities and skills associated with the team projects allow different learning types to excel at different aspects. Thus far, the response from students and faculty about the projects-based curriculum has been positive. However, challenges remain for students and faculty with the transition to new roles and a different way of learning.

INTRODUCTION

The challenges of the complex, global world of the 21st century are compelling educators to rethink traditional engineering curricula. The National Academies of Engineering (NAE) has published several reports, such as *Educating the Engineer of 2020* [1] and *Rising Above the Gathering Storm*[2], that call for innovation in education. The United Nations Millennium Development Goals[3] and the Grand Challenges of Engineering[4] (identified by the NAE) point to imperative issues that require creative and technical minds. Today's generation of incoming students also realize the precarious state of the planet and have the genuine desire to make a difference. In addition, accreditation agencies, such as ABET[5], and industries call for engineering graduates to have a variety of practical, professional skills such as design, communication, teamwork, and ethics.

With multiple factors encouraging changes in engineering curricula and their implementation,

L. Vanasupa boldly submitted and was awarded a National Science Foundation (NSF) Departmental Level Reform Grant[6], entitled "Triple Bottom Line Awareness in Design." The grant allowed the department the time and funding to completely redesign the materials engineering curriculum at Cal Poly, San Luis Obispo. The main goal was to advance the understanding of how to design learning experiences that would equip future engineers for the complex social issues of the 21st century and to assist with greater retention of underrepresented individuals in engineering.

DESIGNING THE NEW MATERIALS ENGINEERING CURRICULUM was a team effort.

Numerous learning strategies were invoked to employ a multi-pronged approach that focused on student learning in context and in a self-directed manner. The faculty would no longer be the "sage on stage" espousing grand theoretical concepts, but mentors in helping students arrive at well-defined project deliverables. The approach to the curriculum is to incorporate two qualities that are critical for engineers in the 21st century: 1) utilizing a systems approach to design and 2) emphasizing ethical, environmental, health and safety, sustainability, social, political, and manufacturability issues. The basic premise is that young people will be motivated to study and apply their creative energies to benefit society if they are aware of the need and know they can make a difference.

The redesigned curriculum incorporates six principles (Figure 1) that have been proven to be effective in achieving higher retention of underrepresented groups of individuals in engineering and promoting deeper learning in the students: 1) providing meaningful context

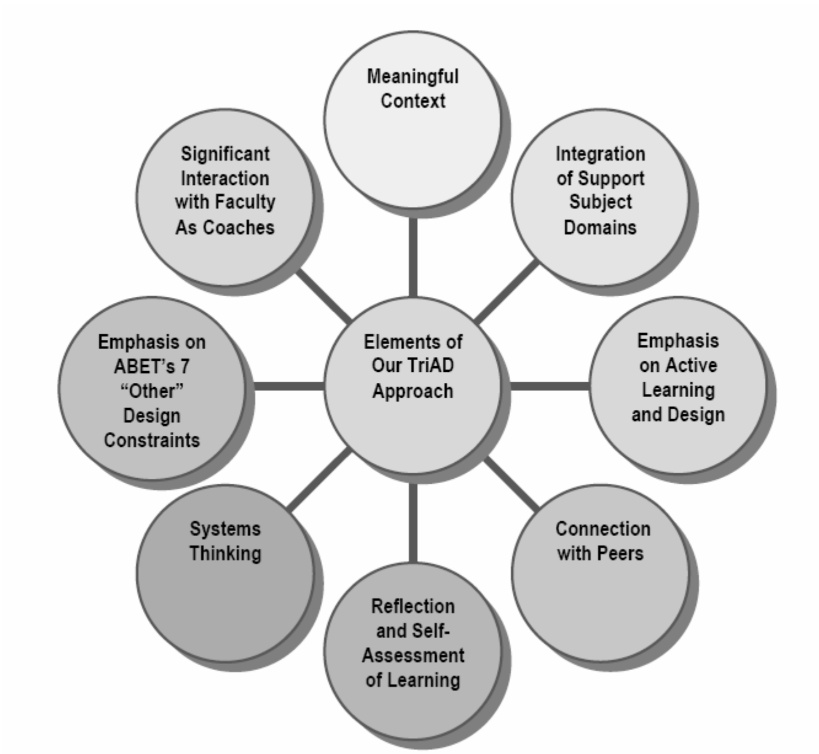

Figure 1. A multi-pronged approach of several different learning strategies was employed to create the new materials engineering curriculum.

(i.e., a "real world" application)[7]; 2) integrating concepts from math, science and technology[8]; 3) emphasizing active learning and design[9]; 4) facilitating meaningful connections among students; 5) promoting reflection and self-assessment of learning[10]; and 6) creating significant interaction between students and faculty, with faculty acting as coaches.

A team of 7 highly motivated and dedicated faculty members designed and implemented the projects-based curriculum[11]. A significant amount of time (two full 40-hour weeks during the summer) was spent by the team to consider the entire 4-year curriculum, rather than retooling individual courses. Utilizing user-centered design methodologies, the faculty developed user personas of students that are characteristic of our program. Through these exercises, we were able to consider a diverse set of learning styles and motivations of students. The user personas allowed the focus of the new curriculum to be centered on student learning. We also identified faculty and student values in order to create an appropriate learning environment. The culture of the department and classroom interactions were also discussed.

During the curriculum redesign sessions, each faculty participant wrote down what they felt were the most important materials engineering concepts and skills to be incorporated into the new curriculum on separate Post-it notes. Together, we then grouped all the Post-it notes into common content threads and themes (Figure 2). Thus, starting with the most important educational objectives, we could then distribute them throughout the curriculum in a thoughtful manner. In essence, we repackaged the core materials engineering concepts into different projects in different courses.

One of the most important components to redesigning the curriculum was the ability of faculty members to let go of existing ideas that "more is better" or that traditional ways of teaching were sacred. Several conversations were held to build common goals among the faculty, such as more students achieving specific and practical learning outcomes. Different modes of teaching (e.g., team teaching) and assessment (e.g., team presentations versus

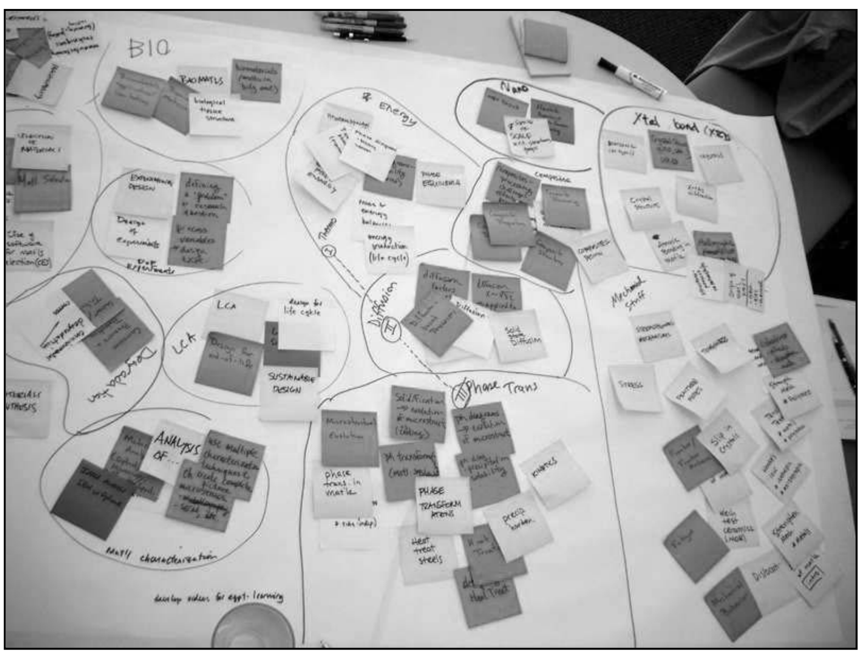

Figure 2. The most important concepts and skills were gathered from the faculty, resulting in common content threads and themes to create the infrastructure of the new curriculum.

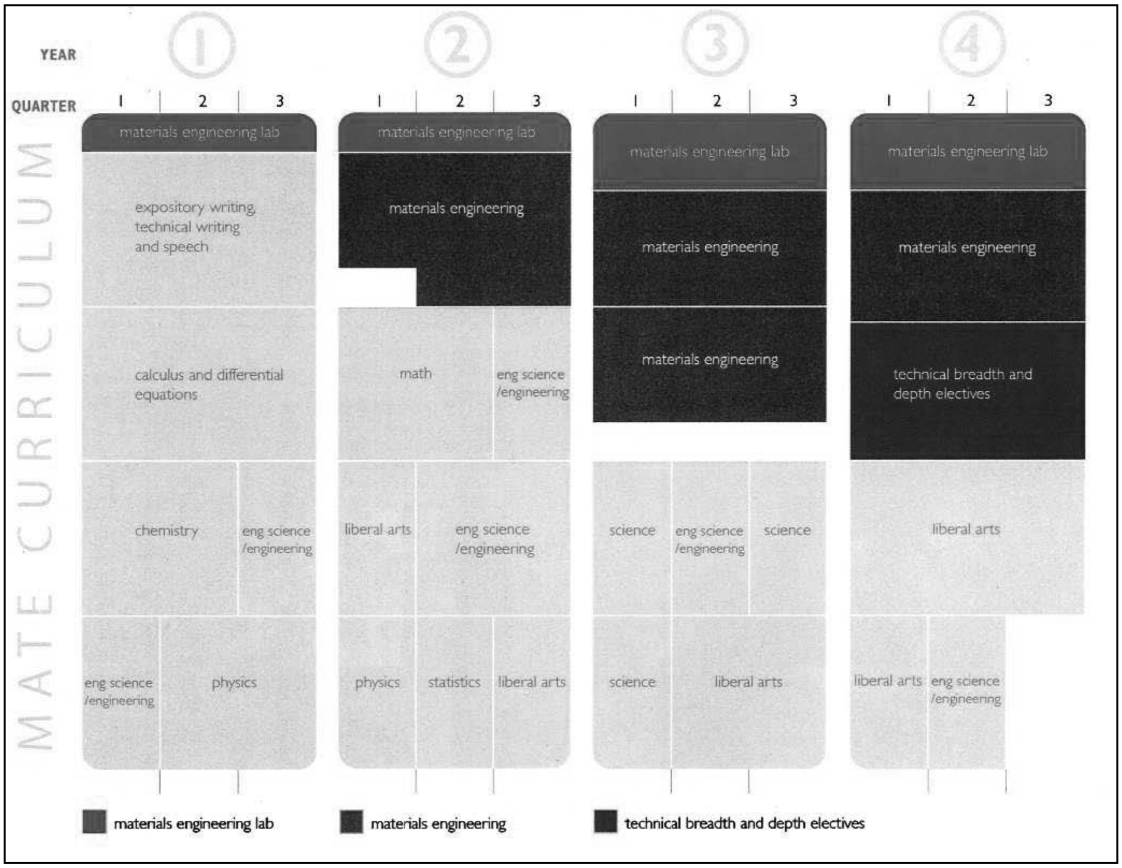

Figure 3. A graphical depiction of the unit designation of the Materials Engineering program at Cal Poly for each quarter of each year within the curriculum.

written tests) were also considered. We decided that while new topics and skills should be covered, basic fundamental concepts were not to be sacrificed. The professional skills, such as teamwork, communication, design, and incorporation of social issues would not be devoted to a single course, but needed to be spread throughout the curriculum for multiple exposure and practice. Expectations of the professional skills would also be stepped in accordance.

The largest change would occur in the 3rd (or junior) year of the curriculum, where most of the students' time is spent on materials engineering courses (Figure 3). In order to best utilize classroom time, we decided to lump together the existing courses of approximately 2 lecture-based and 2 laboratory-based courses per quarter term for 1 new projects-based course each quarter. This block scheduling consisted of 3 hour periods for 4 days each week, and resulted in 12 contact hours/week. The projects courses would also be team-taught by 2-3 faculty. The class time would be spent on mini-lectures and cooperative learning activities, but also allow the students to work on their team projects using campus facilities.

By fortunate coincidence, we also happened to be moving into new building facilities that allowed us to restructure our classroom and laboratory space to accommodate our changes in teaching/learning. The classroom is no longer a regular array of chairs with attached tablets that face a board at the front of the room, but a comfortable, dynamic space with large tables that encourages team-based work (Figure 4). Students sit around these tables to work on cooperative learning activities and to conduct their team projects. Whiteboards are along each wall for students to utilize, and there is no longer an obvious "front of the room" for the instructor. The room can be reconfigured in many different ways, and students have access to the room during non-class time.

Figure 4. A new, modern classroom was designed to promote active learning and team-based work.

MATERIALS ENGINEERING FUNDAMENTALS are put into context of projects, and professional skills are gained in the process

Each quarter for the junior year, a project is crafted to instigate the "need to know" of particular materials concepts. Through the projects, students learn fundamentals of materials engineering and see how they are actually used in the context of something "real." For instance, the "Light Saber project" involves the design, fabrication, and testing of a light measurement system to meet specific design criteria. Different components of the system must interface with each other properly in order to achieve the desired outcome. Student teams use Solidworks modeling (Figure 5), machining, and rapid prototyping while learning about casting, physical metallurgy, phase diagrams, optics, and electrical properties of materials. Issues, such as compliance with waste directives (e.g., Restriction of Hazardous Substances or RoHS), lead-free solders, and outsourcing manufacturing, can be integrated into the projects. Simultaneously, students gain valuable experiences in team work, communication, project management, and self-regulation of time and effort. Greater details about this project are highlighted elsewhere[11,12].

For a different quarter in the junior year, the term project is more open-ended and has student teams designing and investigating an improvement to current biomedical implant technologies. Formal proposals and validation reports are required of each team. Students must research current health issues, patents, and

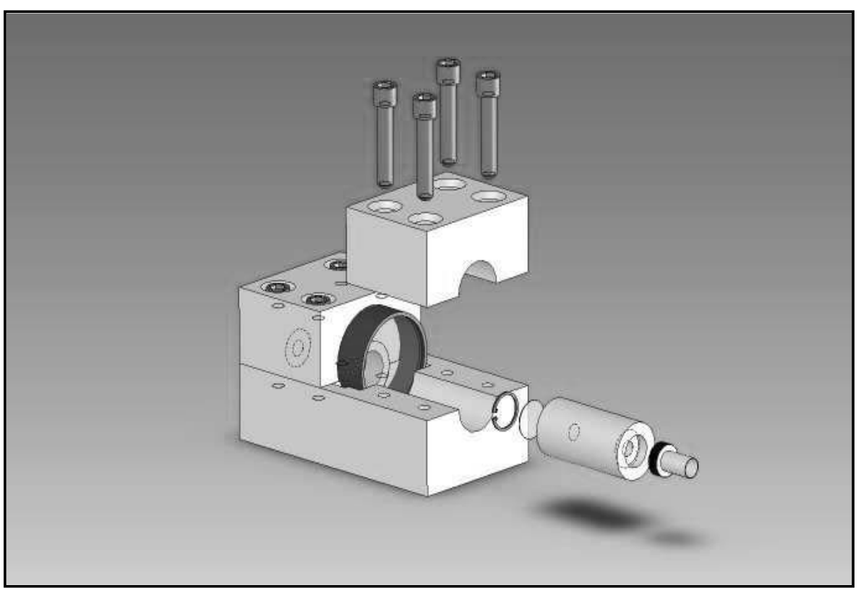

Figure 5. An example of student work using Solidworks to design a light measurement system. Students would then actually build and test the design.

other pertinent background information on their own. Students also use analytical instruments and characterization tools (e.g., scanning electron microscopy, atomic force microscopy, tensile testing) to support their design and project. Meanwhile, they also learn topics such as crystal structures, noncrystallinity, metals, polymers, ceramics, composites, mechanical properties, fracture, fatigue, and corrosion. The design of experiments (DOE) and statistical analysis of data are embedded within the projects. While students have already taken a statistics course as a pre-requisite, they often report that through this particular project, they finally understand and appreciate statistics since they are actually applying statistics to their own project data.

The 2nd (or sophomore) year is a bit more traditional in that there are separate lecture and lab courses. However with the labs, we make an effort to wean them from cookbook lab activities and have them more open-ended. The labs are designed to prepare the students for the bigger projects the following year. They work in teams and they are given autonomy and choices with small projects that might last a few weeks. For instance, they are tasked to explore the solidification and growth of bismuth (Bi) crystals. They develop their own procedures and come to their own conclusions. They refine their study through careful investigations of their own choosing, such as different heating processes, various solidification rates, or selection of different containers. Not all teams end up with the same procedures or results. Through their observations and experiences, the students are much better poised (and eager) to understand the theories of nucleation and growth, heat transfer, solidification, dendritic growth, and crystallography. While some students are a bit overwhelmed at first, others love the freedom to direct their own learning.

Another sophomore lab project has each team investigating the materials selected for a consumer product of their choice. We try to tap into their own interests and let the open-ended project drive what they learn and what instruments they use to support their mini-project. They are required to form questions upfront and develop tests about their materials. Usually with some discussion and pointed questions, the students learn how to frame a problem, and employ different materials characterization techniques. As an example, one team tested the strength of a dollar bill at different conditions. Another team investigated the chemical structure of a new water bottle to see if the advertising claims had any scientific support. Through their projects, students learned how to use different equipment and testing methods, such as tensile testing or Fourier Transform Infrared Spectroscopy (FTIR). A poster was developed for a showcase, and many students were able to learn from their classmates.

Our 1st year (or freshmen) students mainly take support courses (basic math and science), and have only 1 lab in the materials engineering program each term. Here, they learn basic principles of engineering, such as the design cycle, an introduction to Solidworks (a 3D mechanical and computer-aided design (CAD) program), and project management. The year culminates with a service-learning project in which teams of students work with a community partner to fulfill some sort of need for a local non-profit organization. The students do a "needs assessment," come up with a solution, and actually implement the design. The need for good communication skills is readily apparent to the students with these "real" projects. Students also learn about teamwork and individual accountability.

As an example, a team installed a solar water heater for a local school so that young children could wash their hands with warm water and the science teacher could have hot water for experiments (Figure 6). The next year at the same school, our students installed a camera with a weather information gathering system in order to gather instant data to be displayed online. Another team designed and built a greenhouse for an organization that worked with people with disabilities. The students do an amazing job and we see them mature

Figure 6. A team of freshmen design and build a solar water heating system for a local elementary school and science museum to enable young children to wash their hands with warm water and to provide an exhibit to learn about solar power.

through the process. They get early, first-hand experience in how engineers can help society. Such experiences have greatly helped our retention rates.

The open-ended and self-directed nature of these projects highly motivates the students to learn and to produce high quality work. They realize that they are in control of their own learning and that they are gaining valuable, "real world" skills to help them in the future. Numerous students have gained internships and jobs based on their projects experiences. Data from externally validated surveys show that our students who experience the projects-based curriculum score higher in intrinsic motivation scales and readiness for self-directed learning than control groups, and are represented in other papers[11,13].

CHALLENGES REMAIN *and the curriculum continues to evolve*

While the benefits of a projects-based curriculum are numerous, there are also several challenges. Because the classes are different from what students are accustomed to, there can be an adjustment period. Not being able to rely on instructors for the single, correct answer can be unsettling for some. Faculty must also relinquish some control, yet still guide the students. Team teaching among the faculty can also be a challenge.

A great deal of effort is needed to craft the appropriate project that will concurrently satisfy the content learning objectives. We continue to wrestle with the right balance of professional skills versus content. In addition, we have yet to arrive at the best blend of assessment techniques of student learning (i.e., presentations, reports, and exams), as well as the separation of individual student versus team efforts.

Because the projects can be quite open-ended, there is the obligation to have resources on hand (such as stock materials and supplies) and to have functioning equipment. The "need to know" approach requires on-site training of instruments to be available. Technical support and faculty guidance are imperative for successful student projects. Management of different team projects at the same time can be quite challenging for the faculty also. However, the dynamic interactions among the faculty and students, and the powerful learning experiences are all well worth the efforts.

REFERENCES

1. *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*, National Academies Press, 2005.
2. *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*, Committee on Science, Engineering, and Public Policy, 2007.
3. *http://www.un.org/millenniumgoals/*
4. *http://www.engineeringchallenges.org/*
5. *http://www.abet.org/*
6. *http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5462&org=NSF*
7. J.T. Gatto, *Dumbing Us Down: The Hidden Curriculum of Compulsory Schooling*, New Society Publishers, Canada , 1991, pp 1-20.
8. National Science Board Task Committee on Undergraduate Science and Engineering

Education, *Undergraduate Science, Mathematics, and Engineering Education*, National Science Board, Washington, DC, 1986.

9. C.L. Bolbeck, S.E. Campbell, and S.A. Bjorklund, "Grouping in the Dark", *J. Higher Education* **71** 1-16 (2000).
10. J. Duffy, E. Tsang, and S. Lord, "Service Learning in Engineering: What, Why, and How?" *Proc. American Society for Engineering Education Annual Conference*, 2000 (CD ROM).
11. R.N. Savage, J. Stolk, and L. Vanasupa. "Collaborative Design of Project-Based Learning Courses: How to Implement a Mode of Learning That Effectively Builds Skills for the Global Engineer" *Proceedings of the American Society for Engineering Education Annual Conference: Honolulu, HI* (2007).
12. R. Savage, K.C. Chen, L. Vanasupa, "Integrating Project-based Learning Throughout the Undergraduate Engineering Curriculum," Journal of STEM Education, **8**, 1-13 (2007).
13. L. Vanasupa, K.C. Chen, J. Stolk, R.N. Savage, T. Harding, B. London, and W. Hughes, "Converting Traditional Materials Labs to Project-based Learning Experiences: Aiding Students' Development of Higher-order Cognitive Skills", Forum on Materials Science and Engineering Education for 2020, *Mat. Res Soc. Symp. Proc.* **1046E** (2007); *J. Mater. Ed.* **30**, 281 (2008).