It's a Material World
An Engineering Experience for Non-Engineers

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Abstract

Our society becomes more technically complex each day. Key problems faced by society are rarely characterized as problems of science and technology; they are grouped as social, economic or political problems. However, it is clear that social, economic and political issues intersect, and that technological advance and innovation is at the heart of each intersection -- sometimes causing the problems, but more often presenting solutions that elevate the human condition. The thesis of this presentation is that it is incumbent upon the university to ensure that each of its graduates has an understanding of technical issues which will allow them to participate fully in society and meaningfully in the dialogues which will lead to governmental policy decisions in the future. At Cal Poly we have developed a schema to address this need, built primarily around materials engineering topics. The proposed structure is true to the character of the institution and presents non-engineers with a real exposure to technology. Assessment results are presented and discussed.

Introduction

Cal Poly is currently reevaluating its curricula, indeed its very role as a polytechnic university. Part of that reevaluation is a discussion of educational expectations and desired outcomes for non-technical majors. Should liberal arts majors be aware of the strong effect of technology on our culture? Should music majors appreciate the links between their discipline and computers? At first glance, it seems that the answer is a resounding yes. The University Strategic Plan calls for all Cal Poly graduates "*to have acquired knowledge regarding technology, its importance to society and its impacts on natural systems*". Our Visionary Pragmatism Task Force asks Cal Poly faculty to integrate technological and humanistic areas of study: "*Graduates of Cal Poly will possess a uniquely balanced and integrated knowledge and understanding of technology, mathematics, sciences, humanities and the social sciences.*"

The Technological Society

Our society is technologically driven and technology centered. Thus, an understanding of technology, a technological literacy, is a critical prerequisite for full participation as a citizen in the Twenty-first Century world. Indeed, the key public challenges are rarely characterized by government as questions of technology, they are assumed to be socio-economic-political problems. However, key issues often intersect, and technology lies at the center of the intersections, sometimes causing the problems, but more typically offering possibilities for their solution. In its connection to human affairs, technology now defines our culture in much the same way religion or philosophy has in times past. It profoundly changes lifestyles, and can reinforce or collide with our most strongly held values. It modulates the most celebrated passages of our human existence with artificial interventions during birth and on the deathbed. Unseen and often unnoticed, technology dictates our future. Computers, embedded in commercial jets, traffic control systems, cars, lawnmowers, watches, washing machines and toasters, do much of society's rote thinking. These devices and others like them redefine our lives and often produce a cautious and complicated optimism about the future.

The CSU System

The educational imperative of the California State University (CSU) System has its roots in the period between the great world wars and in the GI Bills after the Second World War. With unmatched egalitarian educational fervor, the American public supported the aims of this educationally progressive era. Education was driven by an effort to educate all youth, not just the academically elite, for complete living. Driven by depression era sensitivities, the educational community was urged to serve four goals, self-realization, human relations, economic efficiency and civic responsibility. In the period after W.W.II, these broad educational aims were embellished further in the face of repeated Soviet technical successes - and the implied American educational deficiencies. New emphasis was placed on science and engineering science.

Pressures on the Curriculum

Nationwide, there are tremendous pressures on university curricula. Pressure arises from increased student demand, variegated student preparation, the blending and blurring of social and educational agendas, and diminished resources. In response to these challenges curricula must be examined as a whole, not in a piecemeal fashion. Changes in one portion of the curricula have implications for all others. Curricular renovation cannot be approached in a serial fashion, but rather in a parallel, integrated effort. One must examine curricula to determine what is lacking, and where there is excess. We must guard against professors who, regardless of discipline, fall prey to the first Aristotelian fallacy, that more (particularly more exposure to their subject areas) is better. A companion fallacy is that all learning must occur in a classroom at the university.

Current Curricular Structure and Definitions

GEB requirements in the CSU System are so designed that, taken with the major depth program and elective units presented by the candidate for the bachelors degree, they will assure that graduates of the System have made noteworthy progress toward becoming “truly educated” persons. Curriculum can be divided into three components: liberal arts, science & mathematics, and engineering. In a general fashion, curricula can also be parsed into major courses, support courses, general education and breadth courses, and “free” electives. The confusion and consternation around general education and breadth centers on a single truth: university professors have been singularly unable to define what an educated person should know. General education and breadth courses are typically defined as that mix of courses which students must take, outside their major, to give a broad foundation in liberal arts and sciences - this is not what GEB has come to mean in the CSU System. Interestingly, when faculty nationwide bemoan the diminished emphasis on GEB, they typically allude to science and mathematics requirements not liberal arts requirements. This is not the case in the CSU or at Cal Poly.

As structured, GEB at Cal Poly is anachronistic. It currently reflects a medieval/classical focus on English, history and philosophy that addresses only a portion of what the truly educated college graduate should know. It does not meaningfully address additions to the central body of human knowledge produced during the scientific revolution, and is absolutely mute with respect to technology. The GEB structure defines technical literacy in terms of an ability to use computer programs for word processing and allows requirements for scientific competency to be satisfied by lower division, high school-level courses. In fact, students can be excused from the mathematics requirements of GEB if testing shows that they have a “math-phobia”.

It is also useful to examine the unit requirements for the various disciplines at Cal Poly. Figures 1 and 2 show the units required for graduation as a function of discipline at Cal Poly. Clearly, the engineering disciplines require the greatest unit totals. However, the engineering disciplines, agricultural disciplines and business require the lowest number of units in their own colleges, and fewer units in their own departments than most liberal arts majors. A much greater proportion of the curricula is “free elective” in the liberal arts majors. It is instructive to examine the actual courses taken by typical graduates to assess where these elective courses are taken.

Figure 3, a through d, shows the percentage of the curricula devoted to its various components. Figure 3a and 3b show the portions of the curricula for a typical materials engineering graduate and an idealized graduate from the English department, respectively. Figure 3c and d demonstrate that the actual distribution of courses taken by liberal arts students reflects a more severe parochiality than the idealized distribution. The vast majority of free elective units are taken in the liberal arts student’s own department and college. In fact, in each of the cases shown in Figure 3, English students took almost 90% of their units in one college. Engineering students take less than 50% of their unit load in engineering, 22% in math and science and 28% in liberal arts, a truly broad and general education.

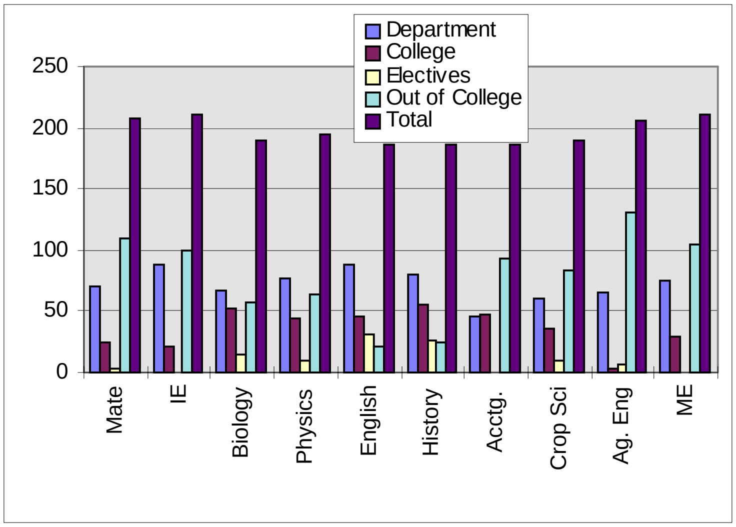


Figure 1. Unit totals required for graduation in various disciplines at Cal Poly

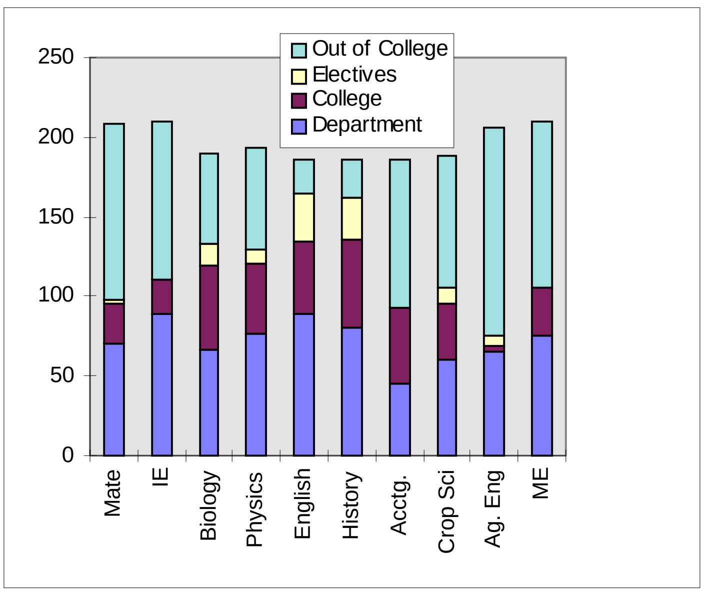
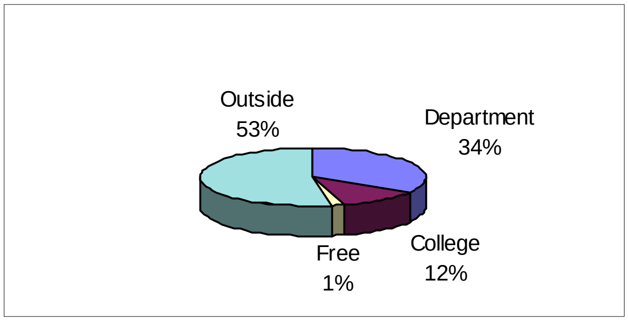


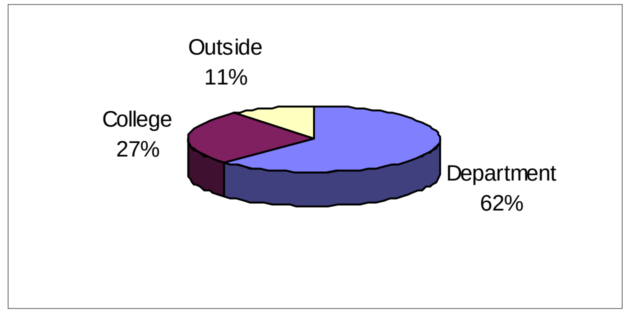
Figure 2. Components of curricula for various departments at Cal Poly

A Response to Fulfill the Need

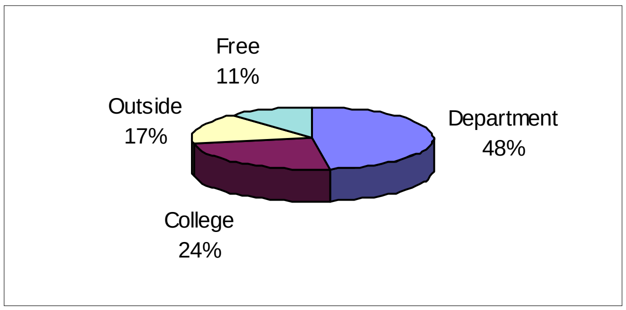
The University delivers an underdeveloped, over-focused GEB program, which ensures students only a basic exposure to a structured subset of the "liberal arts". The stated goal of the GEB program is to ensure that "graduates from the system have made noteworthy progress to becoming truly educated persons." As structured, the program neglects the scientific and technical growth of the students, handicapping them in their quest to become fully educated. This lack is particularly ironic, given that the College of Engineering at Cal Poly, San Luis Obispo has been rated the top public undergraduate college of engineering in the country by US News and World Report.



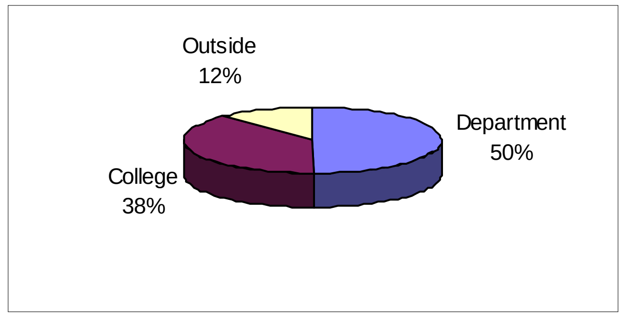
a) Typical Materials Graduate



c) Actual English Graduate 1



b) Idealized English Graduate



d) Actual English Graduate 2

Figure 3. Curricular partitioning in actual student's curricula.

The College of Engineering Technological Literacy Task Force, working with the University GEB Committee, has defined a minimalist technological literacy criteria. To acquire a polytechnic education, Cal Poly graduates should have a fundamental understanding of technology, and the ability to use it to solve problems and make decisions. In the most complete sense students should:

- Understand how technological developments have shaped society presently and throughout history.
- Be able to make decisions based on a trade-off analysis inherent to the decision.
- Be familiar with the operating principles of a variety of technological artifacts and systems.
- Understand how technological developments affect the environment.
- Be able to evaluate what tasks are best suited for computers and implement tasks using basic computer tools.

The proposed model for the technical education component of general education for non-technical majors includes courses which would, in combination, cover these areas. The student leaves this coordinated exposure with an understanding of the relationships between technology and society, with an ability to solve problems using the engineering approach, with a technological literacy and currency, with an educated environmental awareness and with computer literacy. This course is meant to provide an understanding of technology sufficient to augment future life experiences and careers and whet students' appetite for other courses in the technological sequence. It is also meant to help overcome student's attitudes about their own ability to cope with technology, and to improve the accuracy of their impressions of engineers and engineering education (To know us is to love us!). Our guiding vision in implementing the course is to design it for the needs of the students, but not fall prey to presenting a simplified version of an introductory engineering science course.

One problem associated with delivery of "real" technology courses to non-majors is that in many cases students would have to take a minor in science and mathematics to achieve the prerequisites for an introductory engineering course. At Cal Poly this presents less difficulty than some other institutions, we have experience providing introductory engineering exposures to first quarter engineers who lack college level mathematics and science courses. It is only a small extrapolation to present similar courses to non-majors.

An Introductory Exposure
The College of Engineering, in conjunction with the College of Agriculture and the College of Architecture are rectifying this situation. To do so, the Colleges have coalesced to create a four-unit experience (2 lectures, 2 labs each week) which surveys modern technology, both established and growing. The central theme of the course is materials, a natural link between science and engineering, between engineering disciplines and between student's lives and their classroom experiences. This course is the initial exposure which provides students with the background to select subsequent course sequences offered by the participating colleges. A key theme of the course is its hands-on nature, its learn by doing approach, a central character of Cal Poly's technical education. Course modules are self-contained one hour lecture / three hour laboratory experiences. They do not require preparation by the active learner prior to the lecture or laboratory or any post activity. The program endeavors to provide students who would otherwise not be exposed to technology an opportunity to:

- Develop an appreciation of technology based on understanding
- Integrate technology with exposures to other disciplines at the university
- Experience learning in a laboratory setting
- Express creativity through design
- Develop an ability to choose the "best" from a large set of solutions
- Develop the ability to work in diverse groups toward common goals
- Develop the ability to make decisions when confronted with ambiguous and often conflicting information
- Learn in more/better ways
- Deepen their level of understanding and improve intellectual retention
- Participate in the construction of learning tools
- Develop more/different learning styles
- Improve communications skills

An ancillary goal of the effort is to provide teaching and mentoring opportunities for upper-class engineers and graduate students.

The course is presented in a modular fashion, involving teams of faculty and student assistants who present material to the students, and subsequently engage them in laboratory study and open-ended problem solving experiences. We designed this course to pander to the "tinkerer" in all humans. A mapping of human features rendered in proportion to the extent of their coverage on the cerebral cortex provides an interesting figure called the homunculus. This figure has a tiny body with huge face and hands. It provides an explanation not simply for the value of laboratory based instruction but also for our success as a species! Lectures, used alone, are devices that encourage a numbing passivity in students. They can create sterile situations where information passes from the notes of an instructor to the notes of a student without being processed through either person's brain. The vast majority of exposures to technology for the non-technical are lecture based; very similar to the experiences these students have in the remainder of their lecture based liberal arts curriculum. Our approach provides these students with an exposure truly representative of the engineering experience. The following are representative of the modules we present to the students:

Mod 1: Going Mobile!, Americas First Love - Automobiles
The automobile is introduced as a group of interconnected systems. Components of each system are described, and examined, evolution of material selection is discussed. Common problems, their symptoms and solutions are treated. The emphasis here is to expose students to the concept of the laboratory through a "vehicle" all are familiar with on a visceral level.
Mod 2: Mechanical Dissection - A Small Gasoline Engine
The purpose of this experience is to understand the form and function, and manufacturing concerns associated with the production and use of a small four-stroke engine. Students are taken through the dissection in with step-by step instructions and asked to answer questions in their notebooks.
Mod 3: Rapid Prototyping Casts a Long Shadow

This module traces CAD systems for the design of "simple parts" and product realization through the development of 3-D models and molds for casting. Reference is made to the automotive engine block. Students follow the process through the conception of design to final cast prototype, in this case an aluminum golf club head.
Mod 4: Putting It All Together, Art or Engineering?
Students are exposed to the joining process through discussions and practice of soldering, brazing and welding. Importance of joining from "chips to ships", discussion of electronic packaging. Students construct a brazed kinetic sculpture.
Mod 5: It's a Material World
Students are exposed to the basic classes of materials and provided with atomistic and microstructural explanation for their behaviors. Students test materials and record data. Student's correlate microstructure and properties, using process to "engineer" varied properties in materials of the same composition. Mechanical testing a paper clip, statistical significance.
Mod 6: Eddy Current and Millie Amp's Intro to Electronic Materials
Modern engineers have achieved the alchemists dream - they have transmuted silicon into gold (in the figurative sense). Discussion of silicon growing processes and microcircuit fabrication techniques. Properties of electronic materials as a function of temperature, directionality in single crystals.

Other module topics include: Structural Materials - An Engineering Foundation , Gluten, Gluten, Whose Got the Gluten - Biopolymers, Airplane Design - Partnerships That Fly, Landscape Composition, Your Own Web Page!, Pork Bellies Belie Futures!, Mechatronics and Smart Cars, Viva SimCity, Added Value - Links in the Food Chain, Heat and Mass Transfer as a Way of Life, Smog and Sludge, Sewage and Crud, Current Thoughts in Electrical Engineering, Cheaper by the Glass - Viticulture and Enology.

These modules make use of advanced technology in the classroom and laboratory environment. Students make use of communications tools developed by engineers to enhance learning -- the medium is a large part of the message. Data gathering and analysis for laboratory portions of the course are accomplished with state-of-the-art technology. Basic principles are presented with the use of advanced simulation and modeling techniques, thus timeless principles are conveyed in timely fashion.

Each module is focused on an engineering approach to problem solving. Each treats a different theme, and presents a different challenge to the learner. However, in each experience, the experimental method is used as the final arbiter in problem resolution. In addition to factual information specific to each module, learners find that the acquisition of *valid* data, and its *objective* analysis is critical to the optimization process that we call engineering. The project focuses on the use of the engineering method to enhance students capability to absorb, comprehend and relate complex information that, at first blush, often appears ambiguous and occasionally contradictory. Students gain the rudiments of "engineering judgement" through their experience. Through basic data gathering and analysis students develop a "feel" for building valid experiments and for the validity of gathered data. Students were surveyed and tested after appropriate learning events and at course closure.

Modules are presented in a laboratory or studio setting; students are required to work effectively in a group setting - the event and the course survey items provide student with the opportunity to comment on the group dynamic in the learning environment. Students interact with each other and with professors while acting in laboratory teams. The laboratory environment implies more verbal and written interaction than is typical of most classrooms. Many, but not all, of the modules developed include engineering design activities. This is an inherently iterative and integrative process that includes ambiguity, optimization, critical thought, argumentation, ethics, aesthetics, and foresight. Contrary to perception, engineering is not an exact "science". Our survey tools - both post event and post course provide students an opportunity to comment regarding how effectively the course has enabled them to develop "engineering judgment" - our name for attitudes.

Assessment:
A critical part of the course is the evaluation and assessment scheme. Faculty assess student learning and satisfaction after each module, and in a summative way at the end of the course. Student's assessments are correlated with the goals of each module as articulated by the delivery team. We use a suite of assessment tools for this course which includes student journals, scenarios, self and peer assessments, oral presentations/videotapes, classic tests, written reports, student surveys and course profiles.

Course and Module Profiles. Faculty members have completed module profiles for each module and a course profile. These describe the extent to which their modules/course emphasize the various course objectives, the desired abilities, and the classroom activities associated with specific learning goals.

Student Surveys were used to gage student satisfaction at the close of each module and at the close of the course. This questionnaire was built through an extensive validation process to establish the students' perspective on pedagogical practices associated with each module and the course. These surveys were reconciled with the module/course profiles provided by faculty to see if the faculty objectives were met and with the performance assessments to see if there were any correlations between satisfaction and attainment.

Course Portfolios. Students are required to keep a notebook/working journal. These journals are collected and graded after each sequence of three modules is completed.

Scenario-Based Assignments. These tools are based on scenarios generated by faculty and industry advisors that describe typical or critical situations faced by staff in industry. The assignment is a short scenario that sets up the context of an engineering problem--students are asked to describe the process they would engage in to solve the problem.

Taped Observations. Videotape captures students' oral presentation abilities. Pre- and post- videos are made when students make multiple presentations in one course. Where only one presentation is assigned, students complete a self-evaluation and (in addition to the video). In conjunction with the taping, students complete self and peer evaluations of the team. In combination, these tools create a multi-dimensional picture of teamwork skills and provide a method for cross-validation of the tools.

Self/Peer Assessments. These tools create a multi-dimensional picture of teamwork skills. They are used alone and in combination with other assessment tools to report self-proficiency and assign performance ratings to peers. Self/peer reports are useful both for assessment and for facilitating learning by making students more aware of, and responsible for their own development.

The assessment results for the initial sections of this class were instructive. A very strong correlation was found between student satisfaction, measured by survey and laboratory/hands-on emphasis. Likewise a strong correlation was found between student perception of their abilities and the opportunity to experience "hands-on" learning. Passive experience did not fare well in student assessments. Student perception of opportunities to experience "hands-on" learning did not correlate completely with faculty perceptions of the opportunities provided in the modules. The amount of effort exerted in a module correlated positively with student satisfaction and performace. Students accepted some frustration as a normal and necessary part of the learning experience - it actually correlated well with both enjoyment and performance. Usually, students rated performance of peers in their teams as equal to or better than their own. Students were typically less satisfied with their performance than were their instructors.

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