

Triple Bottom Line Awareness in Design (TriAD): Diversifying the engineering profession of the 21st century

The New Curriculum

An overview of the changes

Figure 4 shows a graphical depiction of the scope of curricular changes that we propose to implement in the materials engineering courses (i.e., major courses). A description of the courses follows in the sections below. About 80% of the courses will change significantly, and curricular design principles will be used throughout.

In the figure, the area of each block is proportional to the number of major units. For example, the 110/120/130 lab sequence counts for 3-units total, the sophomore year consists of 3- and 4-unit lectures with 1-units labs each quarter, and the junior year consists of 6-unit lectures and 2-unit labs each quarter.. The general education and engineering support courses are not shown in the figure, since they will remain unchanged. Choosing to focus on the major courses provides students with exposure to the material in different contexts and promotes deeper learning (see the discussion on the section on Intellectual Merit below).

The curriculum depicted in Figure 4 departs significantly from most materials curricula, which often emphasize *materials science*. The first two years emphasize systems thinking and engineering basics. The freshman experience is especially geared toward retention. The junior year emphasizes process design and control, with a balanced mixture of materials science and engineering. As a faculty, we have made a conscious decision to move toward a balanced *materials engineering* curriculum since 80% of our graduates enter industry. It is imperative for materials engineers to be well-versed in the language and practices of engineering and engineering design so that they can play a more significant role in the development of sustainable technological solutions.

Freshman year courses orient the students toward design

The freshman year will consist of a year-long design experience (90 total class hours) in which students work in teams of four or five on two projects. We are in the first year of piloting this course sequence. The first quarter—MATE110—was devoted to designing, building and testing a small vacuum chamber. In this course, we began the process of working toward our objectives, drawing from exercises that have been proposed to promote holistic, systems thinking.¹ For example, the first day begins with the Felder-Silverman learning type indicator test,² an attitude survey, exercises in reflection (*Why did you choose to major in engineering? What do you plan to contribute to society during your career?*), an introduction to the National Society of Professional Engineer’s creed,³ and a viewing of a documentary on alternative transportation called *Energy: Power Shift*.⁴ Each exercise was carefully chosen to assist in achieving our objectives: studying the creed makes it clear that the engineering profession is one of service for the benefit of humanity; the reflection exercise sets the stage for *service learning*, seeing oneself as part of the larger global community, practicing informal communication and developing the ability to assess one’s own learning process; and the documentary activates a vision of the role students can personally play in contributing to

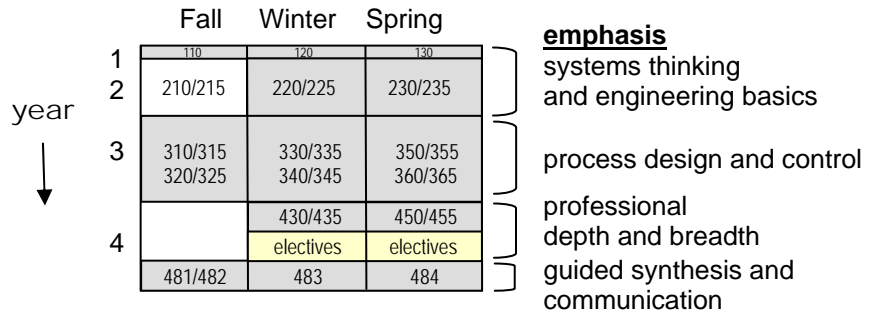


Figure 4. Proposed changes to the **major** courses within the curriculum (~80%)

TriAD Freshman Lab Sequence

110	120	130
Fall	Winter	Spring
<i>Service learning-20 week design project</i>		

Figure 3. Freshman TriAD course sequence

society as engineers. Students gained practice in laboratory documentation; data graphing; linear regression; the design method; the use of simple circuits, sensors and transducers; and the use of data acquisition hardware and software. They also had exposure to manufacturing techniques, computer aided design, systems and project economics.

The second project, spanning MATE120 and MATE130, is to design, build and test a groundwater purification system that requires only renewable energy, for a local family. It is a *service learning* project with an emphasis on the engineer's role in society as one who applies his knowledge for the betterment of humanity. According to Eyer and Giles, service learning contains five principles: connection among students, peers, community, and faculty; continuity of reflection before, during and after the project; context that is real world; challenge that is at the appropriate level of difficulty; and coaching by expert learners.⁵ We have incorporated each of these principles into our course sequence. In 120/130, we also explore the broader issues of environment, sustainability, and awareness of global and social challenges regarding energy and water. In this course the students become more familiar with the product development process and draw upon their knowledge of chemistry and physics.

The primary goals of the 110/120/130 series are to instill in the students what Bandura has called *perceived self-efficacy*, a central psychological attribute that determines one's behavior in an endeavor.⁶ In essence, it is a belief that one is capable of producing one's desired effect. For women, the desired effect may be to better society through one's profession. For first-generation U.S. citizens, the desired effect may be to change their socioeconomic status. Regardless, the statistics on attrition suggest that the freshman and sophomore years are when students are most likely to drop out of engineering.⁷ If students perceive higher self-efficacy, they are more likely to persevere through academic difficulties. According to Bandura's model, one's perceived self-efficacy is bolstered by four

Freshman year Development Team (strengths)
Linda Vanasupa* (materials engineering/engineering education)-lead
Richard Savage* (chemistry/systems engineering)
Katherine Chen* (materials science/chemistry/education)
Susan Ambrose (education/retention)
Diane Long* (public policy)
Julie Zimmerman (sustainability/water quality issues)

*Individuals from Cal Poly.

experiences: performance and accomplishments (or "mastery"); observing and learning from others; freedom from anxiety with respect to work and conduct in one's field; and persuasion and support from others.⁸ The eight elements of best practices (discussed in Intellectual Merit) that we use in our TriAD approach assist in creating these four experiences.

The 110 pilot (Fall 2004) was wildly successful. Normally, we lose about 6-8 of the 36-member freshman class by the winter quarter. At the time of this writing (2/05), we have had seven freshman engineering students initiate the transfer process into our major because of the word-of-mouth popularity of the course. Students participating in the course brought friends and roommates to the final showing of their designs because they were proud of their accomplishments. One female student who transferred into our major wrote "I am thrilled that I switched majors to materials engineering. We have been able to do such cool stuff in class. There is not a minute that I am bored or uninterested. All the hands on work we get to do is so exciting. My friends in other majors tell me that their introduction classes are boring and a waste of time. Getting the chance to learn by doing has made a memorable impact on my experience here at Cal Poly." Incidentally, the students did not know that we were using the eight elements of best practices. Yet each of the eight showed up in the comments by the students in response to the question, "What was the one thing that made this course effective?"

Sophomore year courses build mastery, systems thinking and ethical reflection

Mastery in the second year is accomplished in the laboratory sequence (215/225/235). Here, the students begin to learn laboratory and measurement techniques that are critical to engineers. For example, in order to make intelligent data-based decisions, engineers must have a quantitative knowledge of the limits of the measurement system they are using. In the 225 course, students will conduct measurement capability studies and calibration. The goals are to learn basic measuring techniques and set the stage for statistical process control. These labs require calculus and statistics, reinforcing the principle of transfer.

Biomaterials and ecomaterials have been identified by U.S. and Japanese scientific leaders as the next frontiers of materials development.^{9,10,11} MATE220 (*Materials selection and life cycle assessment*) and MATE230 (*Nanotechnology, human biology, ethics and society*) are new to our curriculum. We have included them to assist in meeting the emerging workforce needs in these areas.

The 220 course has the following features:

- explores the twelve principles of green engineering¹²
- presents cradle to cradle design v. cradle to grave design
- practices the basics of life cycle assessment
- uses software tools for selecting materials for low life cycle impact (*Cambridge Engineering Selector 4*)
- compares closed loop product scenarios and impact on life cycle assessment
- includes case studies for engineering and architecture

By spring 2005 we will have piloted the addition of a number of elements to the 220 course in our existing curriculum. We (BL, KC, RS) have already piloted the limited use of the *CES4* software in 210. It is very popular

with students, particularly mechanical engineering, as it provides a vast, easy-to-access database of materials. Even students who have not taken 210 regularly come to our department and request to purchase a copy of the software.

Faculty Development Team 220- <i>Materials selection and life cycle assessment</i>	
Blair London*	(Materials Engineering)-lead
Katherine Chen*	(Materials Science/Chemistry/Education)
Richard Savage*	(Chemistry/Systems Engineering)
Linda Vanasupa*	(Sustainability/Eng. education)
Susan Ambrose	(Education/Retention)
Julie Schoenung	(Sustainability/Materials)
Barbara Schader*	(Library Science)
Jacqui Isaacs	(Materials Science/Recycling processes)
Dianne Long*	(Political Science)
Susan Robertson	(Sustainable Materials for Architecture)
Julie Zimmerman	(Sustainability in Eng./Public policy)

*Individuals from Cal Poly.

Briefly, the 230 course aims to narrow the nanotechnology literacy gap by exploring four biotechnology nanotechnology examples that represent four different scale levels: 1) cellular level—gold nanoshells for cancer treatment; 2) organ level—tissue engineering of a vital organ; 3) biological systems level—microfluidic glucose sensor; and 4) ecological level—molecular manufacturing.

A key feature of the 230 course is extensive use of diagrams to promote systems awareness and interactions between elements within the system.

Junior year courses build understanding of materials science and practice in process design

The junior year series most significantly departs from the traditional teaching methods. During this year, we plan to schedule courses so that students attend “class” Monday through Thursday from 8-11 a.m. each day. From there, we team teach the courses and remove the boundaries between the classes. Within the last year, we have successfully piloted a number of team teaching projects. The students will complete a series of projects during their junior year. The projects will serve as the impetus for learning the materials science and engineering required to make the product. This learning method would be considered a *just-in-time* approach, where students learn about the principles while working on a project that demands them. If a project requires four consecutive lab periods to complete, we complete it in consecutive class periods, rather than spreading it out over four weeks as is done in traditional labs. The table below lists candidate projects, most of which we have successfully piloted.

The primary work associated with the junior year is ensuring that the learning outcomes for our program are accomplished through the junior year projects. We have generated a list of learning outcomes for the materials engineers. (It can be viewed at www.mate.calpoly.edu/quest). We expect that we will spend the bulk of our time on preparing student reading materials and determining how to present the materials science associated with each project. Each of the projects will follow a framework in which we will explore sustainability, environmental, health and safety, political, social, manufacturability, economic, and ethics issues. Another key feature of the junior year is that it will stress the utilization of statistics for process control and design.

Faculty Development Team: <i>Junior and Senior years</i>	
Blair London*	(Materials Engineering)
Lanny Griffin*	(Biomaterials)
Katherine Chen*	(Materials Science/Chemistry/Education) co-lead
Richard Savage*	(Chemistry/Systems Engineering)-co-lead
Linda Vanasupa*	(Materials Engineering/Sustainability)
Barbara Schader*	(Library Science)
Susan Ambrose	(Education/Retention)
Dianne Long*	(Political Science)
Julie Schoenung	(Life Cycle Assessment/Materials processing)
Julie Zimmerman	(Sustainability in Engineering/Public policy)

*Individuals from Cal Poly.

During the junior year, we will revisit the service learning groundwater purification project. The student and faculty teams for these projects will be expanded to include individuals from environmental engineering and chemistry.

The PIs (KC and RS) have worked together to pilot design activities within a junior-level materials engineering course. RS developed the methodology, based on his career as an engineer (see the biographical sketch of RS for details on his experience). Like many engineering programs,¹³ ours has historically emphasized *analysis* rather than *design*. Although the design exercise was foreign to the students, they highly praised its value as a learning experience. Students commented that they finally felt as if they were experiencing real engineering. Our Industrial Advisory Board has also praised the approach that we presented for teaching design (see letters of support in Supplementary Documents).

From 2000-2002, the PIs (KC, LV and BL) worked together on a laboratory initiative that was designed to integrate concepts of math, science, engineering and technology for sophomore engineering students (*NSF Grant #DUE-9952609*). They created a new paradigm for designing labs and demonstrated that it was effective at reaching students of all learning styles.³⁰ They are familiar with how to design labs to reach students of diverse learning styles.

Senior year courses promote technical depth and breadth and foster professionalism

The senior course offerings serve to provide technical depth. They include courses such as *Biomaterials*, *Microfabrication*, *Electron and X-ray Diffraction*, *Failure Analysis*, *Fracture Mechanics*, and *Corrosion*. We are expanding the offerings with courses in **micro systems technology**. In response to input from our Industrial Advisory Board, we have also broadened our definition of “technical elective;” students can now take courses in *Intellectual Property and Patent Law*, *Statistics for Process Optimization*, and others.

To foster professionalism, we have redesigned our senior seminar/senior project series (MATE481-484). We have converted our senior seminar course (481) from the typical “how to apply for a job” lectures to a substantial, activity-based course that prepares students for the corporate engineering environment. This course, designed by RS, is based on his 20+ years in the industry. It has received rave reviews by our Industrial Advisory Board members. We have also converted our senior project (482-484) into a guided experience that more closely

Candidate Junior Year Projects

Adhesive properties of soft-tissue patches for hernias*
Design of transition T for NiTi stent*
Making fiber optic cable*
Solution hardening of 6061 T6 bicycle crank*
Forging coins*
Creating surface hardness for a gear*
Fabrication of MEMS device*
Optimizing oxidation process for integrated circuits*
Calibration of furnace*
Fabrication of nanoparticle solar cell*
Creation of polymer fuel cell
Casting a space shuttle tile*
Service learning-Water purification* (multidisciplinary group)
*experiments that we have already piloted in some form

resembles real-world project management. A key feature of the final senior project course (484) is that the students present their projects in a professional conference setting. We are teaching (and using) a new approach to engineering presentations described by Alley.¹⁴ This revolutionary approach emphasizes graphical means (images) to communicate ideas and de-emphasizes the use of bulleted lists. Although Alley’s method takes us all outside our comfort zone, the results are amazing; after seven hours of presentations, our IAB members were so impressed that at least one reworked the presentation that he was to give in the following week. Incidentally, we are happy to report that we have gone from a 60-90% senior project completion rate to a 100% *on time* completion rate *for three consecutive years*.

Graphical Summaries of the Changes

The following pages summarize the changes in graphical form. The boxes represent the courses as depicted above in Figure 4.

TriAD Curricular Teams and Goals: Years 1 & 2

Systems Thinking and Engineering Basics

Freshman Year Team (strengths)

Linda Vanasupa* (materials engineering/engineering education)-lead

Richard Savage* (chemistry/systems engineering)
 Katherine Chen* (materials science/chemistry/education)
 Susan Ambrose (education/retention)
 Diane Long* (public policy)
 Julie Zimmerman (sustainability/water quality issues)

*Individuals from Cal Poly.

TriAD Freshman Lab Sequence

110 (1)	120 (1)	130 (1)
Fall	Winter	Spring
Service learning-20 week design project		

Freshman TriAD course sequence, 3 quarters, 1 unit/quarter

Freshman lab sequence

- Orient students toward design
- Engage in Service learning
- Mastery
- Integration of support subjects
- Team building
- Connection with peers
- Forming learning communities
- Reflection for Ethical and Societal Issues
- Systems thinking

222-Materials selection and life cycle assessment

Blair London* (Materials Engineering)-lead
 Katherine Chen* (Materials Science/Chemistry/Education)
 Richard Savage* (Chemistry/Systems Engineering)
 Linda Vanasupa* (Sustainability/Eng. education)
 Susan Ambrose (Education/Retention)
 Julie Schoenung (Sustainability/Materials)
 Barbara Schader* (Library Science)
 Jacqui Isaacs (Materials Science/Recycling processes)
 Dianne Long* (Political Science)
 Susan Robertson (Sustainable Materials for Architecture)
 Julie Zimmerman (Sustainability in Eng./Public policy)

*Individuals from Cal Poly.

TriAD Sophomore Sequence

210 (3)	222 (4)	232 (4)
Fall	Winter	Spring
215 (1)	225 (1)	235 (1)

232 Course

- explores societal and ethical themes
- Develops tools for life-long learning
- Exposes to emerging technologies
- Strengthens critical thinking skills
- Emphasizes systems thinking

235 Lab

- Mastery in laboratory practices
- Materials analysis techniques (metallography)
- Application of statistics in measuring
- Measurement/computer data acquisition

225-Materials Lab II

Katherine Chen (Materials Science)
 Linda Vanasupa (Statistics/Data Acquisition)
 Victor Granados (Manufacturing/Metallography)

222 Course

- explores the twelve principles of green engineering
- presents cradle to cradle design v. cradle to grave design
- practices the basics of life cycle assessment
- uses software tools for selecting materials for low life cycle impact (*Cambridge Engineering Selector 4*)
- compares closed loop product scenarios and impact on life cycle assessment
- includes case studies for engineering and architecture
- Touches on societal and political issues

225 Lab

- Mastery in laboratory practices
- Measurement/computer data acquisition
- Strengthen basic materials science (crystal structure)
- Recognition/exploration of manufacturing techniques (how things are made)
- Application of statistics in measuring

232-Nanotech, biology, ethics and society

Linda Vanasupa (Materials Engineering/Engineering Education) co-lead
 Matthew Ritter (Biology) co-lead
 Dianne Long (Political Science/Technology and public policy)

Lynne Slivovsky (Electrical Engineering/Ethics)
 Peter Schwartz (Physics/Nanotechnology)
 Katherine Chen (Materials Science/Chemistry/Education)
 Richard Savage (Chemistry/Systems Engineering)
 Barbara Schader (Information Literacy/Library Science)
 Jacqueline Isaacs* (Materials Science/Industrial Ecology/Ethics)

*Northeastern University, Boston

235-Materials Lab II

Katherine Chen (Materials Science)
 Linda Vanasupa (Statistics/Data Acquisition)
 Victor Granados (Manufacturing/Metallography)

TriAD Curricular Teams and Goals: Year 3 & 4

Faculty Development Team: Junior and Senior years

Blair London* (Materials Engineering)
 Katherine Chen* (Materials Science/Chemistry/Education) co-lead
 Richard Savage* (Chemistry/Systems Engineering) co-lead
 Linda Vanasupa* (Materials Engineering/Sustainability)
 Barbara Schader* (Library Science)
 Susan Ambrose (Education/Retention)
 Dianne Long* (Political Science)
 Julie Schoenung (Life Cycle Assessment/Materials processing)
 Julie Zimmerman (Sustainability in Engineering/Public policy)

*Individuals from Cal Poly.

Junior Year: Application Driven Courses

- Courses scheduled in blocks (3-4 hours/day, 4 days/wk)
- Learning modules built around engineering applications
- Each Learning module may last several days
- Science integrated into engineering application
- Learning modules team-taught, team-learned

Candidate Junior Year Projects

Adhesive properties of soft-tissue patches for hernias*
 Design of transition T for NITI stent*
 Making fiber optic cable*
 Solution hardening of 6061 T6 bicycle crank*
 Forging coins*
 Creating surface hardness for a gear*
 Fabrication of MEMS device*
 Optimizing oxidation process for integrated circuits*
 Calibration of furnace*
 Fabrication of nanoparticle solar cell*
 Creation of polymer fuel cell
 Casting a space shuttle tile*
 Service learning-Water purification* (multidisciplinary group)

*experiments that we have already piloted in some form

TriAD Junior Sequence

Fall	Winter	Spring
310 (3)	330 (3)	350 (3)
315 (1)	335 (1)	355 (1)
320 (3)	340 (3)	360 (3)
325 (1)	345 (1)	360 (1)

Process Design and Control

- Practice design (materials engineering)
- Use of statistics for process control and design of experiments
- Mastery in applied engineering
- Integration of science in engineering practices
- Team building
- Connection with peers
- Forming learning communities
- Reflection for Ethical and Societal Issues
- Systems thinking
- Integration of ABET "other 7" design constraints
- Strengthening written communication
- Team-based learning
- Project-based learning
- Service learning

TriAD Senior Sequence

Fall	Winter	Spring
4B1 (1)		
4B2 (1)	4B3 (1)	4B4 (1)
<i>Senior Project Sequence</i>		
4xx (4)	4xx (4)	4xx (4)
4xx (4)	3xx -	3xx -
<i>Non-MATE Courses</i>		

Guided Synthesis and Communication

- Building Professionalism
- Strengthening Oral Communication
- Developing time management skills
- Strengthening Independent thinking
- Continuing design practice
- Applying all ABET design constraints
- Engineering mastery

Professional Breadth and Depth

- Strengthening intellectual breadth
- Strengthening intellectual depth
- Strengthening written communication
- Strengthening life-long learning practices

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- ¹ Vanasupa, L. and F.G. Splitt, "Curricula for a Sustainable Future: A Proposal for Integrating Environmental Concepts into Our Curricula," *Proc. Symposium BB, Materials Research Society*, Spring 2004, www.mrs.org.
- ² Felder, R.M., "Reaching the Second Tier: Learning and Teaching Styles in College Science Education," *J. College Science Teaching* 23 (1993): 286-290.
- ³ National Society of Professional Engineers, "Code of Ethics for Engineering: Engineer's Creed," www.nspe.org/ethics/.
- ⁴ *Power Shift: Energy and Sustainability*, DVD published by Worldlink Media, 2003.
- ⁵ Eyler, J. and D. Giles, *Where's the Learning in Service-Learning?* (San Francisco: Jossey-Bass, 1999): 187-209.
- ⁶ Bandura, Albert, *Social Foundations of Thought and Action: A Social Cognitive Theory* (New Jersey: Prentice Hall, 1986).
- ⁷ Goodman Research Group, Inc., "Executive Summary," *The Women's Experiences in College Engineering Project* (Cambridge, MA): v.
- ⁸ Ambrose, S., B. Lazarus, and I. Nair, "No Universal Constants: Journeys of Women in Engineering and Computer Science," *J. Eng ineering Education* 87 (1998): 363-368.
- ⁹ Cramb, A., "The Future of Graduate Materials Science and Engineering," presented at the Spring 2004 meeting of the University Materials Council, National Academies, Washington, D.C., May 23-24, 2004.
- ¹⁰ Cramb, A., "What is the Future Direction for Undergraduate Education in Materials Departments?" *Curriculum Crossroads* (October 2004) www.mrs.org/connections/curriculum.
- ¹¹ *The Seventh Technology Foresight: Future Technology in Japan toward the Year 2030*, National Institute of Science and Technology Policy, Science and Technology Foresight Center, (Tokyo: Ministry of Education, Culture, sports, Science and Technology 2004).
- ¹² Anastas, P.T. and J.B. Zimmerman, "Design through the Twelve Principles of Green Engineering," *Environmental Science and Technology* 37 (2003): 94A-101A.
- ¹³ Moriarty, G. "Engineering Design: Content and Context," *J. Engineering Education* 92 (1994): 135-140.
- ¹⁴ Alley, M. *The Craft of Scientific Presentations: Critical Steps to Succeed and Critical Errors to Avoid* (New York: Springer-Verlag Publishers, 2001).