



Developing Changemaking Engineers – Year Five

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Susan M. Lord received a B.S. from Cornell University in Materials Science and Electrical Engineering (EE) and the M.S. and Ph.D. in EE from Stanford University. She is currently Professor and Chair of Integrated Engineering at the University of San Diego. Her research focuses on the study and promotion of diversity in engineering including student pathways and inclusive teaching. She is Co-Director of the National Effective Teaching Institute (NETI). Her research has been sponsored by the National Science Foundation (NSF). Dr. Lord is among the first to study Latinos in engineering and coauthored *The Borderlands of Education: Latinas in Engineering*. Dr. Lord is a Fellow of the IEEE and ASEE and is active in the engineering education community including serving as General Co-Chair of the Frontiers in Education Conference, President of the IEEE Education Society, and Associate Editor of the *IEEE Transactions on Education (ToE)* and the *Journal of Engineering Education (JEE)*. She and her coauthors received the 2011 Wickenden Award for the best paper in *JEE* and the 2011 and 2015 Best Paper Awards for the *IEEE ToE*. In Spring 2012, Dr. Lord spent a sabbatical at Southeast University in Nanjing, China teaching and doing research. She is on the USD team implementing "Developing Changemaking Engineers", an NSF-sponsored Revolutionizing Engineering Education (RED) project. Dr. Lord is the 2018 recipient of the IEEE Undergraduate Teaching Award.

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Rick T. Olson is Associate Dean in the Shiley-Marcos School of Engineering at the University of San Diego. His research interests lay in engineering student persistence, and applied operations research. He is active in outreach activities targeting underrepresented populations and has received NSF funding to support U.S. military veterans, community college transfer students, and innovative engineering education. He has a B.S. in Mechanical Engineering, and M.S. in Industrial Engineering, and a Ph.D. in Mechanical Engineering with emphasis in Operations Research from the University of Illinois at Urbana-Champaign.

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Chell Roberts is the Executive Dean and former Chair of Engineering for the College of Technology and Innovation at Arizona State University. As Executive Dean, he serves as the College's Chief Operating Officer. As the Founding Chair of Engineering, Roberts led a clean slate design and development of a new engineering program created to be responsive to the latest knowledge on engineering education. He is currently leading the development of highly innovative programs at the intersection of traditional disciplines for a new college model that brings together engineering, science and business in a multidisciplinary fashion focusing on innovation and entrepreneurship. The newly developed curricular model is studio based and highly flexible. As part of the program development, Roberts has created a corporate partners program that has resulted in a high level of industry leadership and funding of multidisciplinary senior projects. Roberts received a Ph.D. in industrial engineering from Virginia Tech, a master's degree in industrial engineering from the University of Utah, and a bachelor's degree in mathematics from the University of Utah. Roberts has published more than 70 technical articles, has guided more than \$2 million of research, provided consulting services to many companies, and served on many national conference organization committees, national review boards, and technical committees. Roberts's primary research and teaching interests are in the area of engineering education, computer simulation, and manufacturing automation.

Dr. Caroline Baillie, University of San Diego

Caroline Baillie is Professor of Praxis in Engineering and social justice. She has held multiple, academic positions in materials engineering and engineering education in the UK, Canada and Australia before joining the University of San Diego. Baillie's specialization is the intersection of engineering and social justice and she has published over 200 books and articles on related topics. She also runs a not for profit



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Dr. Odesma Dalrymple is an Associate Professor and Faculty Lead for the Engineering Exchange for Social Justice, in the Shiley Marcos School of Engineering at University of San Diego. Her professional pursuits are focused on transforming engineering education and its public image; making it more inclusive and socially connected. This mission is partially actualized through her research, which explores the wealth of embodied knowledge, skills and practices that under-represented/marginalized communities can bring to bear on engineering practice. These insights are in turn used to inform the development of asset-based engineering learning experiences for middle and high school populations that predominantly comprise students of color from low-socioeconomic neighborhoods, and the creation of guides on how engineers can collaboratively work with communities on grass roots socio-technical challenges.

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Dr. Leonard Perry (ISE) has research interests in the area of system improvement via quality improvement methods especially in the area of applied statistics, statistical process control, and design of experiments. Dr. Perry consults, instructs, and collaborates on quality improvement projects with representatives from biotech, health care, defense, and traditional manufacturing institutions. He has been an instructor for the Six Sigma Black belt training at the Six Sigma Institute for three years. He is a UCSD Certified Six-Sigma Master Black-Belt and an ASQ Certified Quality Engineer.

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Abstract

This paper describes progress to date resulting from a National Science Foundation (NSF) IUSE/PFE Revolutionizing engineering and computer science Departments (RED) grant at the University of San Diego (USD). We envision engineering curricula and practice that value engineering as a sociotechnical endeavor. This vision of engineering will produce graduates who can address a wider range of societal problems bringing new perspectives to traditional areas. In this paper, we will review our progress towards achieving this vision, including curricular efforts related to a revised canon, a program to develop professional skills and greater connections to professional practice, and the creation of partnerships with industry, students, and community, including other Catholic universities, who value our vision of changemaking engineers.

Introduction

Traditionally, engineering students are trained technically, with less focus on critical examinations of assumptions within engineering practice, and less emphasis on the larger contexts in which engineering is embedded. With funding from a National Science Foundation (NSF) IUSE/PFE Revolutionizing Engineering and Computer Science Departments (RED) grant, the Shiley-Marcos School of Engineering at the University of San Diego (USD) is working to produce and disseminate a model for redefining the “engineering canon” with the goal of developing “Changemaking Engineers”. This revised canon teaches technical skills within a contextual framework that includes humanitarian, sustainability, peace, and social justice perspectives. This requires a curriculum that includes a focus on student teamwork, a greater consideration of social factors, improved communication with diverse constituents, and reflection on ethical decision making and problem solving. This vision of engineering will produce graduates who can address a wider range of societal problems bringing new perspectives to traditional areas.

Summary of Curriculum Development

One of the goals of our NSF RED grant is to: *“Develop the foundation of a revised engineering canon and empower faculty to develop and deliver a professional spine that prepares changemaking engineers.”* Efforts to address this goal include creating new classes and developing lectures, active-learning exercises and assignments that contextualize engineering through social justice, humanitarian practice, peace, and sustainability. We have developed these materials to support our Mechanical (ME), Electrical (EE), Integrated (IntE), and Industrial & Systems Engineering (ISyE) degree programs. New courses include Engineering and Social Justice, Engineering Peace, Community-Based Participatory Apprenticeship, User-Centered Design, and an Integrated Approach to Electrical Engineering. Modules or other content have been incorporated in courses including Circuits, Materials Science, Operations Research, Six Sigma - Process Improvement, and Robotics. Existing courses in the curriculum which incorporate materials designed to help students become Changemaking Engineers by incorporating sociotechnical elements are summarized in Table 1.

Table 1: Summary of Courses with Changemaking Elements *denotes a new course

Year of Students	Course Title	Required (R) or Elective (E)?	Modules (M) or Throughout (T)?
First or Second	User-Centered Design* (ENGR 103)	R for all engineers	T
Second	Electrical Circuits (ELEC 201)	R for EE, IntE, ME; E for ISyE	M
Second	Integrated Approach to Electrical Engineering* (GENG 288)	R for IntE; option for ISyE	M
Second	Statics (MENG 210)	R for all engineers	M
Third	Engineering and Social Justice* (GENG 350)	R for IntE; E for others	T
Third	Engineering Materials Science (ENGR 311)	R for IntE, ME, ISyE	M
Third	Operations Research (ISYE 340)	R for ISyE	M
Third	Six Sigma – Process Improvement (ISYE 335)	R for ISyE	M
Fourth	Heat Transfer (MENG 400)	R for ME	M
Third, Fourth, or Fifth	Community-Based Participatory Apprenticeship* (ENGR 351)	E for all	T
Third, Fourth, or Fifth	Engineering Peace* (GENG 494)	E for all	T
Third, Fourth, or Fifth	Introduction to Robotics (MENG 445)	E for all	M

We have published an overview of some of these efforts [1, 2]. We have also published details about modules in existing courses including Statics [3, 4], Heat Transfer [5] and Robotics [6] in Mechanical Engineering, Circuits [7, 8] in Electrical Engineering, Operations Research [9] in Industrial & Systems Engineering, and Introduction to Materials Science [10, 11, 12]. In addition, we have described courses on User-Centered Design (UCD), Engineering and Social Justice [13], and an elective on Engineering Peace [14, 15, 16, 17]. Below we highlight work done in the last year (i.e., Spring 2019 – Spring 2020).

GENG 288- An Integrated Approach to Electrical Engineering

GENG 288 is a second-year required course for Integrated Engineering students. Industrial Engineering (ISyE) students may choose to take it as an engineering science breadth course. This course includes a lecture and laboratory. It is designed to provide a broad introduction to electrical engineering concepts and topics. This course was taught for the first time with six students in Spring 2019.

Social, environmental, and economic context was integrated into the course via a *Design for the Future* module. The module is framed around a course-long student project where students were asked to choose a technology of interest to them that relates to electrical engineering. In homework assignments, students identified particular technologies they were interested in and two potential social implications. They chose a wide variety of items including Tesla batteries, solar cells, football helmet communication devices, and tidal-powered turbines. In class, students were introduced to and discussed the impacts of lithium mining and hazardous waste relating to solar panels, interrogating how we determine and define sustainable technologies and how these can be improved. Students then wrote a memo in which they analyzed a quantitative problem around cadmium leaching in a solar farm, and considered assumptions and knowledge gaps. Then, students participated in an in-class exercise to consider the design implications of who benefits, who pays, and who is excluded across the product life-cycle in relation to their chosen technologies for their projects. Finally, students presented and submitted reports on their chosen technologies in which they examined the implications for design, stated technical considerations, explored the potential innovation of the technology and its personal significance to them.

ENGR 311 – Engineering Materials Science

ENGR 311 is a third-year introduction to materials course taken by engineering students throughout our school. Several new modules have been developed for and used in one section of this class in Fall 2017 [5, 6], 2018 [7], and 2019. Note that our 2018 ASEE paper was awarded best paper in the Materials Division.

In 2019, we incorporated a new module, *The Last Straw*. Prior to the module, students were introduced to information on an existing environmental problem (i.e., the great Pacific garbage patch) and answered homework questions on how traditional engineering interventions have been inadequate to solve the problem. The first part of the module focused on the material properties of single-use plastic straws that have resulted in their ubiquitous and environmentally deleterious use. Students were then introduced to the Social Impact Analysis (SIA) tool, implemented in Microsoft Excel, which uses United Nations Environment Programme (UNEP) and the Society of Environmental Toxicology and Chemistry (SETAC) reports to evaluate the social impact of a product's lifecycle. Based upon the social impacts revealed through SIA, students made and justified recommendations on changing the material of the straw or the nation the material originated, was manufactured, or disposed in. In the second part of the module, groups of students considered the unique design needs of a marginalized stakeholder who relies on the material properties of single-used plastic straws (e.g., individuals with strength and mobility issues) to recommend an alternative material for the straw (e.g., paper, metal, silicone). In doing so, they considered the larger economic, environmental, and social impacts of their material recommendation, and also consider how engineering design and public policy can unintentionally exclude vulnerable populations.

ISYE 335 – Six Sigma – Process Improvement Methods

ISYE students are required to take ISYE 335 in their third year as one of their key courses for process improvement. The course introduces a structured methodology for improving processes in manufacturing, healthcare, banking, or any organization with some form of operations. Social, environmental, and economic context was integrated into the course via a lab module. The module is framed around a tile making process in Sri Lanka. The students utilize process

improvement tools and methods to improve a tile making process with a twist. They have to make recommendations and improvements framed in the context of a small village in Sri Lanka with social constraints. Students present their recommendations to their peers in class with rich technical and non-technical discussions.

ENGR 351 Community-Based Participatory Engineering Apprenticeship

To support the increasing number of students who wish to work with both local and international communities, and develop their capabilities related to the social and environmental context of engineering practice, a new elective was offered in Spring 2019 with the explicit intent to facilitate student exposure to and ability to work in a participatory way with community groups. The course facilitates connections between the theories and praxis of engineering that are socially and environmentally just. Students develop skills of critical thinking, questioning assumptions about privilege and power and dominant frames of thinking and being, as well as an awareness of non-dominant, non-Western paradigms. They are then introduced to a local community project and work in teams to co-define, with the community, a problem brief that is socio-technical in nature. The problem definition stage of engineering design is in focus because this is the area least well understood by students, who prefer to delve straight into answers. In this class, they are forced to hover in the definition stage long enough to begin to ask questions about what the real problem is, as defined by the community, which might be different to what they had initially considered.

In its inaugural year of 2019, the class worked with Debbie Stein, STEAM (Science, Technology, Engineering, Art, and Math) teacher at the Viejas Band of Kumeyaay Nation, together with her fifth grade class, to address the environmental pollution of rivers and oceans, to which the Kumeyaay have a particular connection. The class also teamed up with Tijuana River National Estuarine Research Reserve to consider how to address the pollution of the estuary. Connecting the Kumeyaay care for the oceans and rivers and the engineering students' technical knowledge, and then adding the complexity of the cross border US/Mexican national park (which is all part of the traditional and unceded territory of the Kumeyaay Nation), engaged the students and partners in a multicultural community development program in the canyon regions adjacent to the estuary.

Professional Skills Development – Industry Scholars Program

The Industry Scholars Program (ISP) is a year-long industry immersion program for outstanding first- and second-year engineering undergraduates established by the industry advisory board of our engineering school with goals of providing an industry perspective on professional skills that would include the abilities that normally one may not acquire in a typical engineering school. We launched the program in Spring 2017 [18]. Activities include industry-led monthly professional skills workshops and industry site visits during the academic year and summer internships. The industry-based advisory board has designed evening workshops that have included emotional intelligence, intellectual property, social justice, ethics, negotiations, professional communication, and professional etiquette. In addition, students receive career advisement workshops in resume writing, interviewing, and internship success skills.

An Industry Scholars Mentorship Program has also been developed [19]. The goals of the mentorship program were to provide continued industry mentorship for students who had completed the ISP program and to foster organic one-on-one mentorship relationships between industry and students to further their professional skills education. The mentoring program matches students who have completed the ISP program with mentors from Industry based on characteristics of the mentors and mentees and common goals. Through this program students developed goals for their mentorship with the mentors and then met (sometimes virtually) to discuss goals and progress.

An assessment of the first year of the mentorship program found that students had significant gains in their pre- and post- perceptions of knowledge and skills in business ethics, their ability to describe and discuss a variety of engineering related industries and employment types, the level of their interaction with industry, the quality of their resumes, and their access to other students, faculty, and industry partners. Asked about their experience, one student wrote: “The skills I learned in the program directly applied to my internship and helped me feel more prepared for my participation in industry.” Another student discussed increased confidence by stating: “The ISP has made me more ready for the professional world in every sense. I feel more confident communicating and navigating the professional world.” Another student expressed their change in perceptions of engineering and networking: “After having completed this program, I not only developed a network for advice, but the numerous workshops and speakers made me realize the diversity of what it means to be an engineer.”

We believe these programs exemplify how industry partnerships in higher education are vital to increased preparedness of engineering graduates.

Engineering Exchange for Social Justice (ExSJ)

In March 2019, the Shiley Marcos School of Engineering launched the *Engineering Exchange for Social Justice* (ExSJ) with support from this RED grant and a USD Strategic Initiatives Grant [20]. ExSJ defines a new approach for engineering and community partnerships. Through the mutual exchange of expertise, technical skills are combined with contextual, cultural and historical knowledge of the community to identify real needs. Community defined ‘problem briefs’ can then be turned into actionable student assignments, design projects, research theses or extracurricular pro bono engineering projects that are supported by local professionals.

In November 2019, we hosted our first ExSJ Student and Faculty Scholar Award luncheon. The awards act as both an incentive for individual students and faculty members to engage in social justice community work, as well as to undertake professional development in support of this work, which we provide on an ongoing basis. The inaugural awards were presented during a luncheon which attracted about 50 people from across our campus as well as the local community. Dr. J. A. Mejia received a Faculty Scholar Award celebrating his work with communities in San Diego and Argentina. The work of eight undergraduate students was also celebrated with ExSJ Student Scholar Awards. These included Integrated Engineering, Industrial and Systems Engineering, Computer Science, and Biology majors.

ExSJ has also launched a community award program. To support communities to present their ideas to the exchange we have a three step process. The first step is for communities to attend a community forum. If communities have a suggestion for a project, and students and faculty are interested in supporting them, the team may submit an application to our project development grants. This funding is to enable the team to meet and consider the framing of a project, what it would entail, and the technical and financial support it would need. The final step is to apply for an ExSJ seed grant. These grants fund a small project and support an interdisciplinary capstone student design team for one year.

During the last year (AY2019-2020) a seed grant was awarded to support working with Tijuana River National Estuarine Research Reserve to address waste pollution in the Tijuana Estuary. The project team is helping to develop a community business adjacent to the estuary that will prevent excess garbage from reaching the river by up-cycling the waste into domestic products. This project aims to embody the cultural identity, values, and assets of the community in establishing its unique up-cycling solution based on the Waste-for-Life method co-developed by SMSE faculty member and team co-supervisor Dr. Caroline Baillie. [<https://www.wasteforlife.org/>].

Other community partners that have engaged with ExSJ include an afterschool STEM program on the Kumeyaay Viejas Band Reservation; Advancing Students Forward, a bi-national non-profit that provides financial and academic enrichment for students in middle school through college in Colonia Tecolote, Tijuana; and a Blind Community Center in San Diego.

Another aspect of intellectual exchange is facilitated by the ExSJ Visiting Scholar program where scholars from around the world spend time at USD working with faculty, students, and the ExSJ. We have had two Visiting Scholars from Colombia so far. These valuable experiences helped the USD community to learn about Colombia, specifically community work and the peace process, and see how different kinds of engineering can be applied through a social justice lens. This in turn helps other faculty and students begin to broaden their understanding of what we envision when we describe engineering and social justice.

“Developing Changemaking Engineers Symposium” USD 2020

As part of our dissemination and to expand our community of partners, we hosted a symposium on “Developing Changemaking Engineers” on January 17-18, 2020 at USD. About 40 engineering deans and educators from 14 Catholic universities across the nation gathered to learn more about the activities of the USD RED grant and other work to promote engineering and social justice. The symposium included presentations and collaborative activities.

The symposium opened with an interactive activity exploring “What is Engineering?” facilitated by Susan Lord, professor and chair of integrated engineering and Alex Mejia, assistant professor of integrated engineering at USD. Dean Chell Roberts then provided an overview of the USD RED grant and the symposium goals.

Presentations included

- “Engineering for Social Justice: A Multi-space and Multi-strategy Approach for Transforming Engineering Education,” Juan Lucena, professor and director of Humanitarian Engineering at the Colorado School of Mines and Alex Mejia, assistant professor of Integrated Engineering at USD
- “Engineering and Social Justice: Facilitating Learning Through Exchanges with Communities” Caroline Baillie, professor of praxis, Integrated Engineering, USD and Odesma Dalrymple, associate professor of Industrial and Systems Engineering, USD
- “Projects, Modules and Degree Programs,” Camille George, associate dean of Engineering, University of St. Thomas
- “Changemaking Curricula: Modules in Engineering Classes,” Ming Huang, professor of Mechanical Engineering, Susan Lord, and Rick Olson, professor of Industrial and Systems Engineering and associate dean, USD

Day one ended with a poster session where participants shared key aspects of how they are developing Changemaking Engineers on their campus, what they would like to do next in this area, and explored areas of collaboration. On day two, participants focused on these potential collaborations. Ideas included jointly developing new ideas for additional curricula and content that represents engineering at Catholic universities, seeking funding for future gatherings focused on developing Changemaking Engineers at Catholic universities, and exploring mechanisms for sharing this work broadly.

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