Developing Changemaking Engineers – Year Four

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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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Susan M. Lord received a B.S. from Cornell University and the M.S. and Ph.D. from Stanford University. She is currently Professor and Chair of Integrated Engineering at the University of San Diego. Her teaching and research interests include inclusive pedagogies, electronics, optoelectronics, materials science, first year engineering courses, feminist and liberative pedagogies, engineering student persistence, and student autonomy. Her research has been sponsored by the National Science Foundation (NSF). Dr. Lord is a fellow of the ASEE and IEEE and is active in the engineering education community including serving as General Co-Chair of the 2006 Frontiers in Education (FIE) Conference, on the FIE Steering Committee, and as President of the IEEE Education Society for 2009-2010. She is an Associate Editor of the IEEE Transactions on Education. She and her coauthors were awarded the 2011 Wickenden Award for the best paper in the Journal of Engineering Education and the 2011 and 2015 Best Paper Awards for the IEEE Transactions on Education. In Spring 2012, Dr. Lord spent a sabbatical at Southeast University in Nanjing, China teaching and doing research.

Michelle M. Camacho, University of San Diego

Michelle M. Camacho is Professor of Sociology at the University of San Diego. She began her career at UC San Diego in 1999 as a postdoctoral fellow at the Center for US Mexican Studies, and later as a UC Faculty Fellow in Ethnic Studies. In 2015-16, she returned to UC San Diego as a fellow of the American Council on Education. As a bilingual/bicultural Latina, Camacho has 30 years of experience in higher education advocating for underrepresented groups and first generation college students. For over a decade, her work on institutional transformation has received funding from the National Science Foundation to examine and address inequities in higher education, specifically as they relate to Science, Technology, Engineering and Mathematics (STEM). She served the NSF ADVANCE grant initiatives as a co-Principal Investigator, working to improve practices to recruit and retain women of color in STEM and enhance institutional climate at USD. Other current research grants support pathways for veterans in higher education, and the NSF program called, "Revolutionizing Engineering & Computer Science Departments." Her co-authored books include The Borderlands of Education (with Susan Lord), Mentoring Faculty of Color, and Beginning a Career in Academia: A Guide for Graduate Students of Color. She is past-Vice President (2017) of the Pacific Sociological Association, and an appointed consultant to the American Sociological Association's Departmental Resources Group. Fluent in both quantitative and qualitative research methodologies, her research uses theories from interdisciplinary sources including cultural studies, critical race, gender and feminist theories. Central to her work are questions of culture, power and inequality. She is affiliated faculty with the Department of Ethnic Studies, Women's and Gender Studies, and Latin American Studies.

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Ming Huang received his MS in University of Rhode Island and Ph.D. from the Ohio State University in Mechanical Engineering. He is currently professor and chair of mechanical engineering department at USD. His research interests are coordination and computer aided design optimization of of robotic mechanisms, theory and practices of inventive problem solving and engineering pedagogy.

Dr. Leonard A Perry, University of San Diego

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.

Dr. Breanne Przestrzelski, University of San Diego

Bre Przestrzelski, PhD, is a post-doctoral research associate in the General Engineering department in the Shiley-Marcos School of Engineering, where she innovatively integrates social justice, humanitarian advancement, and peace into the traditional engineering canon.

Before joining USD in August 2017, Bre spent 9 years at Clemson University, where she was a three-time graduate of the bioengineering program (BS, MS, and PhD), founder of The Design & Entrepreneurship Network (DEN), and Division I rower. In her spare time, Bre teaches design thinking workshops for higher education faculty/administrators at the Stanford d.School as a University Innovation Fellow, coaches a global community of learners through IDEO U, and fails miserably at cooking.

Dr. Chell A. Roberts, University of San Diego

Chell A. Roberts is the founding dean of the Shiley-Marcos School of Engineering at the University of San Diego. He assumed his duties in July of 2013. He was also recently appointed as the Associate Provost of Professional and Continuing Education.

As an engineering dean at USD, Dr. Roberts has led the development of a new school of engineering, developing innovative engineering space, growing a world class faculty, and creating a base of industry and community partners. He also led a team to win a $2 Million NSF Grant to revolutionize engineering education. The award focuses on creating ”Changemaking Engineers” and seeks to transform the engineering mindset to infuse sustainability, social justice, peace, and humanitarian practices in the context of and professional skills of engineering.

Before joining USD, Roberts served as the Executive Dean of the College of Technology and Innovation at Arizona State University. While at Arizona State University, Dr. Roberts also had the opportunity to design an engineering program from a clean slate based on the study of best models of undergraduate engineering programs in the world.

Dr. Roberts received a PhD in Industrial Engineering from Virginia Tech, an MS Industrial Engineering degree and BA Mathematics degree from the University of Utah.

Developing Changemaking Engineers – Year Four

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). Specifically, this paper focuses on curricular development to support a redefined "engineering canon" that teaches technical skills within a contextual framework that includes humanitarian, sustainable, and social justice approaches. This broader perspective of engineering practice will produce graduates who can address a wider range of societal problems bringing new perspectives to traditional areas. We highlight examples from a range of engineering courses throughout the undergraduate curriculum. Some of these efforts incorporate modules in traditional engineering classes including Electrical Circuits, Materials Science, Operations Research, and Heat Transfer. We have redesigned our User-Centered Design class to more explicitly engage with these topics. In addition, we have developed innovative new courses that integrate a sociotechnical view of engineering throughout the course including Engineering and Social Justice and Engineering Peace. We have also replaced our external evaluator team with an external advisory board (EAB) of experts in engineering education and change management. Our EAB have begun to help us reimagine how we can be more effective at meeting the objectives of the grant and truly revolutionizing engineering education.

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 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, sustainable, and social justice approaches. 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 consequences of decisions and solutions. This broader perspective of engineering practice will produce graduates who can address a wider range of societal problems bringing new perspectives to traditional areas. In this paper, we review our recent efforts towards achieving this vision, focusing on the development of curricular materials

Summary of course materials developed and used at our university

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." To date, we have pursued this by creating new classes and by developing lectures, active-learning exercises and assignments that contextualize engineering through social justice, humanitarian practice, peace, and sustainability. A future goal of the project is to disseminate the course materials so that they can be adopted by other schools. This section summarizes some of the content that has been developed to date. More details including student response and instructor reflection are available in many of the cited publications.

ENGR 103 – User-Centered Design (UCD)

UCD is a required course for engineering majors taken during the second or third semester. In addition to the design principles that are often covered in most first-year design classes, UCD introduces students to the idea that engineering is not just a technical field but rather a sociotechnical and sociopolitical endeavor, by introducing strategies for developing designs that emphasize how users interact with the final product [1]. For example, when evaluating the efficacy of a design, students reflect on questions such as: Could this design create controversy? What are the lasting positive and negative implications/ impacts/ consequences of the innovation? Who is the technology designed for? Who are the designers/ decision makers? and Who does the technology provide a dis/advantage for? These types of activities, among others, help students learn to think critically about design in general. Then they apply this critical lens when working on their own design projects in the course. Projects focus on the needs of people who are very different than most engineering students including visually impaired or aging populations.

The collection of activities in this class and the perspectives introduced has allowed the class to be approved to satisfy the introductory Diversity, Inclusion, and Social Justice requirement in the University Core Curriculum. The designation of this requirement has lessened some student and faculty resistance to the class.

ELEC 201- Electrical Circuits

ELEC 201 is the sophomore-level introductory circuits required of electrical engineers, and taken by most other engineering students. The social consequences of technical engineering decisions are seldom discussed in traditional engineering classes. That is especially true of second year classes where students are introduced to the analytical techniques used in engineering. To help students place engineering practice into a sociotechnical context, three modules have been developed for one section of this class in Spring 2018.

The first module, entitled "Conflict Minerals", makes students aware that materials commonly used in electrical devices (such as Tantalum in capacitors) often come from countries where wars are fought over the resources [1, 2, 3]. Students are then encouraged to consider how they could minimize the use of conflict minerals as engineers and conduct research to learn about measures actually taken by companies to reduce the use of these materials.

The second module addresses the potential for recycling electronics and includes a visit to an Electronics Recycling Center (ERC). Afterwards, students reflect on their experiences with used electronics and their observations at the ERC from the perspective of an engineer who may be designing devices, or recovering the materials. That perspective is likely to be different that the consumer orientation that most students have.

The third module "Responsible Social Innovation" centered on the Sunshine Box [4], a product of 1773° Innovation Company that aims to provide safe and reliable solar power charging for cell phones in countries that do not have stable electrical grids. For their last homework assignment, students calculated some key values for circuits inside the Sunshine Box. The founder then came to class, discussed their homework responses, and shared her experiences in making design decisions for this innovation.

More details on these three modules can be found in [3].

ENGR 311 – Engineering Materials

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] and 2018 [7].

The first module "Bring in Your Trash," was inspired by an activity at Stanford University [8] where students create something with the trash they collected over a week. This was adapted into a module to help students think about materials from the perspectives of sustainability, social responsibility, cost, life cycle and use [5]. Students collect their own trash for a week and bring it to class. Teams of students then sort bags of trash using given different sorting criteria. such as material property or life cycle. During subsequent discussion, students explain their sorting methods, and contrasted how similar materials get sorted differently depending on the criteria used. They then reflect on how these mindsets affect how people think about the materials they use and how those mindsets might lead to unexpected, undesired consequences. Finally, students reflect on their obligations as engineers to think about the responsible use of materials from more than one perspective.

In Fall 2017, a biodesign challenge module was implemented [6]. Students worked in teams to design a wrist brace, with teams having different clients including an elderly person in Guatemala, an astronaut, or a soldier on a battlefield. By changing the client, students become aware that it isn't sufficient to know the mechanical properties of materials they might consider. They also need to consider the sustainability, cost, life-cycle, and availability of the materials along with the life-style of the user. This exercise emphasizes the importance of evaluating materials beyond their measurable technical properties in the design process.

In Fall 2018 [5], the "Bring in your Trash" module was revised based on student and instructor feedback from the first offering. It focused a bit more on the impact their personal waste contribution has on a regional scale. Additional modules were developed and integrated into the course. One module had students go on a tour of or watch a video about a city-wide recycling processing center to observe the sorting processes that materials undergo once they are discarded. Through this tour, students were able to recognize some of the challenges of current waste disposal and recycling practices. Another module welcomed a guest expert to share their experiences with the global impact of waste disposal and the relative privileges that persist in developed countries. Students explored the idea of "designing for the dump". The last module had students explore materials for use in a commercial product, a beverage container, inspired by the regional and global challenges they were previously exposed to in the course.

GENG 350 – Engineering and Social Justice

This course is a required course for third-year Integrated Engineers and is an elective for other engineering majors. In *Engineering and Social Justice,* students analyze the historical, social, political, and economic impacts of engineering in marginalized communities. Students consider the contemporary contexts and impacts of the designs, systems, processes and products surrounding and involving engineering and engineers [1]. Some of the activities used to achieve the goals of the course include critical reflection essays on topics of feminism and microaggressions; an analysis of the intersecting axes of privilege, domination, and oppression; and a community engagement project analyzed through the lens of Critical Race theory.

This class has been determined to satisfy the advanced Diversity, Inclusion, and Social Justice requirement in the University Core Curriculum. Because of the extensive writing required, it also satisfies the Advanced Writing requirement in the core.

ISYE 340 – Operations Research

ISYE 340 is a junior-level course in operations research (OR) emphasizing building and analyzing and deterministic optimization models. To help students understand how OR can be applied beyond the business and production-related areas that appear in most texts and cases, two Changemaking cases have been written. For each scenario, teams of students develop and solve a model, perform sensitivity analysis and write a one-page executive summary of their recommendations along with supporting analysis.

In the first case, students develop a model to select a sustainable energy action plan for a college campus that considers tradeoffs between different strategies for reducing CO_2 emissions (e.g. LED lighting or Photovoltaic panels). Students must allocate a limited budget while considering tradeoffs between 5-year and 20-year energy costs and savings, and the CO_2 reduction achieved. The policy that provides the best 20-year return underperforms in five years, and student must reconcile these conflicting results.

In the second case, students develop model that could be used by a consortium of philanthropic foundations to determine which community proposals should be funded. Students must consider whether it is better to allocate resources to meet the goals of the individual foundations, or whether it would be more effective to pool their resources and aggregate their priorities. Because the decisions that optimize the individual goals are not the same decisions that optimize the combined goals, different student teams make different recommendations for different reasons.

An additional set of assignments has been developed to help student reflect on the potential that OR has to create positive societal change [9]. First, students individually define what they think it means to be a *Changemaking Engineer.* They are then put into teams where they are asked to develop a group definition, then identify at least 10 situations where the methods of the course could be used to develop a model that could be used to produce change. After receiving feedback on the proposed scenarios, the students select one scenario and outline what information they would need to be able to build a model that addresses the scenario.

MENG 400 – Heat Transfer

Two modules were introduced into this senior-level mechanical engineering course to give students an opportunity to solve problems with real world constraints that are related to the goals of the RED project [10]. The first module, used in the section of the course that introduces convection, begins with the analysis of a conventional electric water heater in the USA. This problem is representative of one that might appear in most heat transfer classes, but students are also required to calculate the cost of keeping the water heater running constantly in the US where electricity is always available. After successfully solving that problem, the scenario moves from the USA to Lebanon and students are asked to solve the problem again. This requires students to grapple with different constraints as they explore the feasibility of having a water heater running in a location where electricity is not available 24 hours a day.

The second module is designed for the Heat Exchanger section of the course and is framed around a successful student-faculty project that our university implemented in the Dominican Republic to provide hot water for personal use to a community [11]. Students first use their understanding of heat transfer to develop an underlying model for the performance of the system. A homework assignment expands this model and requires further analysis. Students then work in small teams to design improvements to the system while considering limitations that may be imposed by the location in a developing region with limited resources. Together, these projects help students to understand that similar problems may have different solutions depending on the location, resource availability and other factors.

MENG 445 - Introduction to Robotics

Courses on robotics typically emphasize technical knowledge; little time is spent addressing the social or ethical implications of the field. At USD, MENG 445 is an elective that is taken by junior and senior mechanical engineers. To engage students to critically think about the sociotechnical implications of robotics, a course project module, named 'Robots at Your Service', was developed [12]. The module encourages students to consider questions such as: Will robots limit our relationship with our fellow humans, or isolate us even further from one another? Do present a danger to our society? Who feels the impact of technology changes, and who gets to make decisions about technology? The module includes an assignment that has students reflect on a robotics film of their own choice and discuss it from the perspective of the questions posed. This work is complemented by technical research assignments that result in students identifying new opportunities for robotic applications in the context of these social and ethical considerations.

ENGR 494 - Engineering Peace

An engineering faculty member and a faculty member from a school of Peace Studies have developed this course that focuses both on the design and use of drones while cultivating empathy across disciplinary boundaries. [1, 13, 14, 15]. The class is taken as an elective by engineers (usually seniors) and graduate students in Peace Studies. The first third of the course is a combination of mini-lectures and class or group discussion about disciplinarity, technology, and social change. The second third of the course is spent building a small drone where engineers experience some modest technical difficulties while assisting non-engineers for whom drone construction may present new challenges. The final stage of the course is spent developing a pro-social use for a drone and preparing a project pitch to deliver at the semester's end. This

phase relies on modules designed to help students think about rapid prototyping, develop a minimum viable product, and pitch their ideas to others. Besides gaining new information about the design and use of drones, both the peace and engineering students learn to work effectively with people from a radically different discipline than their own.

Future Curricular Work

In addition to these course materials that have been used in classes, additional classes are being developed including a course on "Community-based Participatory Engineering Apprenticeship," "An Integrated Approach to Electrical Engineering," "Cities, Communities, Organizations, and Urban Design using GIS," and "An Integrated Approach to Energy" funded by an NSF IUSE grant [16].

Refocusing and future plans

During the first three years of the grant, we used the services of an external evaluator. Their primary role was to summarize the work we had done and assess how we were progressing towards the goals of the grant. An important element of their work was intended to be assessing how the culture of the school may have changed by the end of the grant.

As the fourth year started, the project team found ourselves questioning whether we were using our time, energy, and funding effectively. We felt we were pursuing some activities because they were mentioned in the proposal, and not because they were effective. We found our biweekly meetings often centered around managing tasks rather than thinking deeply about developing changemaking engineers. We decided we would benefit from an advisory board who understand our vision and the engineering education community enough to help us prioritize our work and be more effective. So, after obtaining approval from our NSF program officer, we replaced the external evaluators with an external advisory board (EAB).

The new advisory board comprises three members who are all engineering educators. Among them, they have broad and deep understanding of engineering education, change management, and administration having served as department chairs, heads of school, and NSF Program Officers. They understand our vision of engineering as a sociotechnical endeavor and the importance of helping our students to see this. They are keenly aware of the traditional culture of engineering education and the obstacles to changing the status quo.

Initially, we thought the board would assess the work we have performed, help us identify where we have been the most effective, and suggest new ways to meet the goals of the grant. However, the first Skype calls with the EAB revealed that we didn't just have an advisory board, we had a team of academic life coaches who would be thought partners on this journey of change. In the calls, and during a two-day on-site visit, they have asked probing questions about our personal motivations for pursuing this work and what we hope to accomplish beyond the RED grant. They have helped us to step away from the day-to-day management of the grant activities and think about how "Developing Changemaking Engineers" involves more than changing course content. It requires revolutionary changes engineering education culture including how faculty work with and treat each other, how university administration values and rewards people who

take chances to create change, and how departments, schools, and universities work with the communities they serve. The EAB has encouraged us to worry less about the number of course modules we develop and the number of faculty who attend workshops, and to think more about the root causes of the current culture of engineering and engineering education and how we might start to address those root causes that are preventing students and faculty from being changemaking engineers.

We were fortunate to attract this team of visionary and empathetic leaders. The change from evaluators to an advisory board has been transformative for our project team and grant. Because of the board's guidance, we anticipate that spring 2019 will be a period of transition. Our short-term goal remains to make the curricular materials we have prepared for our classes available to other faculty who want to introduce changemaking themes into their classes. We will also continue to plan to host a conference on developing changemaking engineers in 2020 and continue to support faculty who want to revise their classes and develop new ones. But we expect that we will be doing that in new ways that we have yet to discover. Given the challenge of revolutionary change, we think that other teams attempting such change including other RED teams might benefit from some of our lessons learned about external evaluation.

Summary

The University of San Diego is making progress toward establishing a foundation for a revised engineering canon through the development of courses and modules that contextualize engineering with social justice, humanitarian practice, peace, and sustainability. These changemaking ideas have been introduced in about ten classes with more under development. The scope of classroom experiences that have been developed ranges from entire classes devoted to changemaking themes (e.g. GENG 350), multiperiod modules (e.g. ENGR 311 and ELEC 201) to individual homework assignments (e.g. MENG 400, ISYE 340). The next phase in the development of course materials will be to compile them for dissemination for adoption by other educators.

We have also replaced our external evaluator team with an advisory board who have extensive experiences in engineering education and change management. They have helped to begin to reimagine how we be more effective at meeting the objectives of the grant and truly revolutionizing engineering education.

Acknowledgements

The authors would like to acknowledge the revolutionary work of our USD colleagues who have worked to develop course materials and use them in classes. This work by Drs. Caroline Baillie, Diana Chen, Austin Choi-Fitzpatrick, Odesma Dalrymple, Gordon Hoople, Imane Khalil, Alex Mejia, Elizabeth Reddy, and Breanne Przestrzelski is what makes the project a success. The Advisory Board members, Drs. Alan Cheville, Donna Riley, Linda Vanasupa deserve recognition for helping us to reimagine what we can do through this grant. Finally, we thank the students who have worked through the new materials and provided helpful criticism that makes us more effective.

This work is supported by the National Science Foundation's Revolutionizing Engineering and Computer Science Departments (RED) program through Award #1519453.

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