Developing Engineering Leaders: An Organized Innovation Approach to Engineering Education

Dr. Sara Jansen Perry, Baylor University

Sara Jansen Perry is an assistant professor of management in the Hankamer School of Business at Baylor University. She teaches human resource management and negotiation courses. She earned her PhD in 2009 from the University of Houston in Industrial-Organizational Psychology, also earning the Meredith P. Crawford fellowship in I-O Psychology from HumRRO that year. She won the Engineering Management division best presentation award at the 2015 ASEE conference in Seattle. Sara conducts research in innovation, leadership, and stress-related topics.

Dr. Emily M Hunter, Baylor University

Emily M. Hunter, Associate Professor of Management in the Hankamer School of Business at Baylor University, earned her Ph.D. in Industrial-Organizational Psychology at the University of Houston in 2009. She teaches negotiation and organizational behavior and conducts research on work-family conflict, employee deviance and servant leadership.

Mr. Ed Frauenheim, Great Place to Work Institute

Ed Frauenheim has been a writer, editor and commentator for nearly 20 years. He has focused on the intersection of work, technology and society. He is co-author of two books: Good Company: Business Success in the Worthiness Era and Organized Innovation: A Blueprint for Renewing America’s Prosperity. Ed currently is Director of Research and Content at Great Place to Work Institute, which works to improve society by transforming workplaces. Prior to this role, he worked as a journalist at publications including Workforce magazine, CNET News.com and The Oakland Tribune. He has contributed articles to publications including Fortune, Wired, Salon.com, The San Jose Mercury News, The San Diego Union-Tribune and The Seattle Times.

Ed’s stories have earned honors from American Business Media, the American Society of Business Publication Editors, the Associated Press News Executive Council of California and Nevada, and the Northern California Chapter of the Society of Professional Journalists. In addition, Good Company earned the 2012 Gold Nautilus Book Award in the Business/Leadership category.

Ed has spoken to live and broadcast audiences on subjects including innovation strategy, corporate social responsibility and the future of work.

Along with Organized Innovation co-authors Sara Jansen Perry and Emily M. Hunter, Ed delivered a day-long workshop on the principles of the book to affiliates of the Baylor Research and Innovation Collaborative at Baylor University.

Ed graduated cum laude from Princeton University with a degree in History. He earned a Master’s Degree in Education from the University of California at Berkeley.

Ed lives in San Francisco with his wife and two kids.

Prof. Steven C. Currall, Southern Methodist University

Steven C. Currall is Provost and Vice President for Academic Affairs at Southern Methodist University. As Provost, he oversees the university’s academic activity including seven academic units: Cox School of Business, Dedman College of Humanities and Sciences, Dedman School of Law, Meadows School of the Arts, Lyle School of Engineering, Perkins School of Theology, and Simmons School of Education and Human Development. He is also responsible for additional units that include the Office of Research and Graduate Studies, Central University Libraries, satellite Campuses in Plano, Texas and at Taos, New Mexico, the Office of Assessment and Accreditation, the Office of Institutional Research, the International Center, the Center for Teaching Excellence, the Division of Enrollment Services (undergraduate admission, office of financial aid, student financials office, and the Registrar), and several student programs such as the SMU honors groups. At SMU, Currall is the David B. Miller Endowed Professor. He
also holds academic appointments as Professor of Management and Organization in the Cox School of Business. He is also Adjunct Professor of Psychology in Dedman College of Humanities and Sciences and Adjunct Professor of Engineering Management, Information, and Systems in the Lyle School of Engineering. Currall previously worked at the University of California, Davis (UC Davis), where he served as Senior Advisor to the Chancellor for Strategic Projects and Initiatives and as Professor of Management. As Chancellor’s Senior Advisor, Currall co-chaired campus-wide strategic visioning exercises to position UC Davis as the “University of the 21st Century.” He also led planning for an additional campus in the Sacramento region, which included the academic strategy, financial plan, fundraising plan, analysis of physical facilities, organization of advisory groups, and liaison to the Academic Senate. He has served as the Vice Chair of the Board of Directors and member of the Executive Committee for the 10-campus University of California system’s Global Health Institute. He also served on the Boards of Directors of the San Francisco Bay Area Council and the California Life Sciences Association. Additional leadership experience included serving as the Dean of the Graduate School of Management at UC Davis, leading the School to the highest ranking in its history; Endowed Chair holder; founding Chair of an academic department; leadership of seven centers/institutes, and campus-wide service roles as Chair of the Task Force on Faculty Salary Equity, Chair of the Strategic Review of Human Resources, Chair of Board of Directors of the Ecosystem for Biophotonics Innovation, Vice Chair of Chancellor’s Blue Ribbon Committee on Research, and member of the Vision of Excellence committee. A psychological scientist, Currall has conducted research and taught for nearly three decades on organizational psychology topics such as innovation, emerging technologies, negotiation, and corporate governance. At the invitation of the U.S. President’s Council of Advisors on Science and Technology, Currall was a member of the Nanotechnology Technical Advisory Group. He has been a grantee on $21,533,893 in external funding of which over 78% came from refereed research grants from the National Science Foundation (NSF) and National Institutes of Health. Currall was lead author of a book on university-business-government collaboration entitled, Organized Innovation: A Blueprint for Renewing America’s Prosperity (Oxford, 2014). Based on a study funded by the NSF, the book is the culmination of a 10-year research project on interdisciplinary research involving science, engineering, and medicine. He has served as a member of several editorial review boards such as Academy of Management Review, Academy of Management Journal, and Organization Science. He is a Fellow of the American Association for the Advancement of Science. Currall has served as a member of the boards of BioHouston (interim Vice Chair; Executive Committee; chair of Governance Committee), Leadership in Medicine, Inc., Nanotechnology Foundation of Texas, and Interferometrics, Inc., a venture-funded medical device start-up. He has been quoted over 600 times in publications such as the New York Times, Wall Street Journal, Washington Post, Financial Times, Business Week, British Broadcasting Corporation (BBC) television, and the Nightly Business Report on public television.
Developing Engineering Leaders:

An Organized Innovation Approach to Engineering Education

Abstract

In addition to providing technical expertise in their respective fields, engineers are increasingly assuming leadership roles in industry, government, and non-profit organizations. We draw from lessons learned in our decade-long study of the National Science Foundation (NSF) Engineering Research Center (ERC) program to provide both a theoretical framework and tangible recommendations to educators interested in engineering leadership development. In addition to producing impressive and economically important innovations, the ERC program is an exemplar model for educating engineers who are also uniquely positioned as leaders. ERCs expose students to real-world practices of engineering, providing them with on-the-job training in critical leadership and technical areas. Students often act as the “glue” that binds together ERC researchers from different domains, thereby catalyzing communication across disciplines, organizations, job levels, and cultures. ERC-trained students also learn how to manage projects, engage in strategic problem-solving, and implement decisions as they pursue interdisciplinary project work throughout the engineering curricula. In particular, a 2006 NSF study found that 60 percent of the new courses introduced through ERCs had multidisciplinary content as well as a systems focus. Industry has recognized the competitive advantage of graduates from ERC educational programs; nine in ten company supervisors report that former ERC students and graduates are better prepared to work in industry than equivalent hires without ERC experience. Nearly 75 percent of those supervisors say employees with ERC experience were better able to
develop new technologies. In addition, hiring students with ERC experience is one of the most prized benefits to companies working with the ERCs. We draw on lessons learned from our decade-long study of the NSF ERC program to propose the Organized Innovation Model for Education, which provides guidance for educators and scholars interested in developing highly skilled engineers who are also leaders.

**Introduction**

How do we transform engineering students into leaders? This is a dilemma many scholars in engineering leadership programs are attempting to answer as engineers continue to be key contributors in the ongoing, high-stakes innovation race for global economic competitiveness. In this paper, we propose a theoretical framework and provide evidence-based, actionable recommendations for an education model designed to transform engineers into leaders during their undergraduate and/or graduate education experience. To do so, we apply a theoretical model, Organized Innovation, to the design of engineering education. This model is based on our decade-long study of the National Science Foundation-funded (NSF) Engineering Research Center (ERC) Program, which has witnessed great success in graduating science and engineering leaders over the past three decades.

In the pages that follow, we first briefly illuminate the impetus for engineers to learn leadership skills, and why this is particularly valuable early in one’s career. Then, we outline the success the ERC Program has enjoyed in developing science and engineering leaders. Third, we describe our research methods that led to our conclusions. Finally, we introduce the Organized Innovation Model for Education, which is based on features of the ERC Program and other
similar multi-disciplinary, multi-institutional university research centers (MMURCs). In this final section, we provide specific recommendations for educators, university leaders, and policy makers on how educational systems might be enhanced to produce a better prepared, leadership-ready engineering workforce.

Section 1: The Problem

A common lament is that when an organization’s best engineer is promoted to a leadership role, that organization loses the best engineer and gains the worst leader. The skill sets required for engineering jobs and leadership roles are often distinct; engineers learn technical principles required for their specific engineering discipline, whereas effective leaders require strategy, communication, persuasion, motivation, and myriad people skills. To perhaps oversimplify, these are left brain versus right brain jobs, with little overlap. Still, some engineers seem naturally suited for leadership roles, as they naturally excel at the right brain, social and strategic skills. The question for educators is, how can we develop these skills in every engineering student, even those who do not naturally seek to lead?

As one response to this problem, engineering management and engineering leadership programs have emerged. These programs feature almost startling diversity, in that there seems to be no real standard for how leadership skills are instilled in students. Offerings range from voluntary workshop offerings (for example, Brigham Young University’s Weidman Center for Global Leadership) to full undergraduate or graduate degree programs (for example, Duke University’s Master of Engineering Management Program). In some instances, partnerships are created with other colleges who have expertise in leadership issues, such as business. In almost
all cases, students only opt in, which creates a self-selection bias. That is, it seems likely that those who are naturally inclined toward a leadership skill set are the most likely consumers of such offerings. Thus, the problem remains on how to help traditional engineers develop leadership skills while they also learn the technical skills for their field.

Solving this problem is more important than ever as the world becomes increasingly reliant on technology, and as leadership in innovation becomes a mandate for countries to lead in the world marketplace\textsuperscript{1,2}. Tech-savvy leaders are needed to manage these complex innovation creation efforts, which increasingly require more inter-disciplinary and inter-institutional collaboration. We submit there is no one better to fill those roles than engineers who have a complex technical skill set \textit{and} a leadership skill set. But to provide a pipeline of such uniquely positioned leaders, a revised leadership development model is needed, which educates all engineering students to better prepare them for this new reality.

\section*{Section 2: A Quiet Success Story}

A program that has seen great success in preparing scientists and engineers to also be leaders is now in its fourth decade – the National Science Foundation (NSF) Engineering Research Center (ERC) Program. The university-based ERC Program began in 1985 with a mission to strengthen the competitiveness of US firms through better education and research. It has seen great return on the modest investment in it over the past three decades – both in terms of technology advances and in equipping America’s science and engineering workforce. From 1985 to 2009, about $1 billion in federal funding was invested in about 50 ERCs, and those ERCs have returned more than 10 times that amount in a wide variety of technology innovations\textsuperscript{3,4}. 

\textsuperscript{1}Reference 1
\textsuperscript{2}Reference 2
\textsuperscript{3}Reference 3
\textsuperscript{4}Reference 4
Examples include advanced mobile phone platforms, breakthroughs in electronics miniaturization, foundational techniques in biotechnology and nanotechnology, and even development of an artificial retina that restores sight to the blind.

In addition to these innovative technological successes, the ERC program also has provided a model of highly successful engineering education. ERCs expose students to hands-on, contemporary engineering activities through frequent interaction with industry partners and academic researchers from a variety of disciplines and institutions. The ERC program also integrates knowledge derived from each center’s interdisciplinary projects into engineering curricula, making it more systems-focused.

Students who are educated as part of an ERC are better prepared, both technically and socially. A 2004 study (see Figure 1) found that nearly nine in ten company supervisors rated former ERC students and graduates as better prepared to work in industry than equivalent hires without ERC experience. Nearly 75 percent of those supervisors said employees with ERC experience were better able to develop technology. In addition, our study of the ERC program found that hiring students with ERC experience is one of the most prized benefits to companies working with the centers. Supervisors consistently commend ERC graduates’ ability to communicate, work with others, and engage in problem-solving for large-scale problems. In other words, their leadership skills are a welcome complement to their technical skills.

Figure 1
Clearly, ERCs are role models for how to create advanced engineering educational experiences. But what are the specific aspects of these centers that produce such a positive experience? Perhaps surprisingly, we did not find any explicit leadership courses in our examination of ERCs. Instead, ERCs provide continuous, informal, hands-on educational experiences that inherently teach leadership skills. Indeed, many ERC researchers and leaders described students as the “glue” bonding the many players within each research project together, and these students develop leadership skills because of the unique role they play in a complex, multidisciplinary and multi-institutional research team, even as they complete their educational degrees. We acknowledge that most traditional engineering departments may not have such large-scale multi-disciplinary projects to use as inherent educational experiences. But the lessons from ERCs can be generalized and applied to enhance leadership development, even in traditional academic departments.

In the next section, we briefly describe our research methodology and how we arrived at the conclusions in this paper. Then, we outline the Organized Innovation Model for Education, which we developed based on a decade-long quantitative and qualitative research effort. The proposed model describes and prescribes a paradigm shift for the engineering educational experience, with key features that can be implemented across any university and traditional engineering department, even those that do not have any ERC-like organizational structure.

Section 3: Research Methodology

The present study sought to maximize methodological rigor and continue to build on the practice of combining qualitative and quantitative data\(^5\). Methodological rigor was maximized in this study by utilizing a multi-source, multi-method data collection, combining qualitative and
quantitative data collection into a single field-based, individual- and organizational-level study. Combining these types of data adds an extra level of contextual detail and interpretability to the results of the study\textsuperscript{5,6}. Because all types of data possess disadvantages as well as advantages, it is most appropriate to find a balance in a combination of multiple types of data collection\textsuperscript{7}. This practice increases the extent of discovery, making research more methodologically sound.

To begin, we conducted semi-structured interviews of ERC representatives (students, faculty, and staff, including ERC leaders) and NSF officials who oversee the ERC program. We recorded all interviews using an audio recording device, and then transcribed all interviews and cross-checked with the notes we took during the actual interviews. This was all in an effort to understand the context and the primary issues facing the centers. We visited eleven ERCs in person and interviewed multiple representatives from those centers (ranging from graduate students to the ERC directors). We conducted phone interviews with at least one person from every other active ERC. We also attended three consecutive ERC annual conferences, in which we spent a great deal of time attending sessions, presenting our own research and ideas, attending discussion groups, and talking with individuals one-on-one.

We used information from these experiences to develop an online survey with approximately 120 items. We sent invitation emails to approximately 2300 research faculty, center directors, industry liaisons, administrative staff, graduate and undergraduate students, and post-doctorates across 22 active ERCs, asking them to consider completing the survey. The directors of the ERCs also sent emails drafted by the research team to encourage participation. In total, 839 people completed the survey (37\% response rate).

In addition to survey data, we also collected five years of ERC annual reports directly from the NSF. These were filed by ERCs annually to the NSF program office. They contained
information on technology transfer outputs, personnel, students, education milestones, strategic plans, and much other information about the current status of the ERC. We followed up approximately five years later with in-depth case studies of three of the originally studied and still-active ERCs. These involved in-depth, semi-structured interviews with multiple representatives at each ERC, designed to gain more insight on themes we uncovered through the previous research phases.

One central theme was a desire by leaders to better understand how to lead and motivate “employees” in these unique hybrid environments, where industry and academic colleagues collaborate across disciplinary, university, and organizational boundaries\textsuperscript{8,9,20}. Our program of research aims to address this overarching question, and the present paper tackles this question from the specific perspective of leadership development among a highly-technical workforce.

**Section 4: The Organized Innovation Model for Education**

In this section, we describe the Organized Innovation Model for Education, which contains three strategic pillars, Channeled Curiosity, Boundary Breaking Collaboration, and Orchestrated Commercialization (see Figure 2 for an illustrative summary). These are guiding tenets that can be adopted by any university or academic unit that wishes to better prepare science or engineering graduates to be leaders in the workforce. Within each strategic pillar, we provide specific prescriptions for implementation in engineering programs. The end goal of our work is to help academic leaders design educational systems that produce capable engineers who are also prepared to lead organizations and people.
Channeled Curiosity

The first pillar, Channeled Curiosity (CC), is defined as the orientation of basic curiosity toward relevant and useful outcomes. Traditional educational systems are notorious for teaching basic principles and theories, but failing to link that basic knowledge to applicable skills\(^{10}\). The active learning movement has attempted to address this by encouraging practical, hands-on activities in the classroom for students to apply theoretical concepts immediately, and therefore
have a higher-impact (more engaging and memorable) learning experience. Through these experiences, students collaborate with team members, manage projects, and even communicate results to members of the class, which enhance leadership skills even while reinforcing technical concepts\textsuperscript{10,11}.

The ERC Program promotes CC in its educational programs by involving students in active research projects from the early days of their education. Many researchers we interviewed described students as key connection points for projects and professors across disciplines and departments. Professors involved in the ERC also integrate the systems focus (i.e., big picture of the research projects in the ERC) back into the classroom\textsuperscript{3}. So students have a reciprocal experience, which enhances learning and skill development in both technical and leadership realms.

We propose four principles, focused on specific elements of the student experience, to help universities integrate the tenet of CC into engineering education programs. First, we propose that engineering programs teach students to \textit{Lead Strategically with Vision}. Although strategic planning is not something often embraced by academics, a plethora of research, including our own examination of ERCs, suggests it is a powerful tool for setting and achieving goals\textsuperscript{12}. Engineering programs can teach students the fundamental principles of strategic planning, which includes writing mission and vision statements, making a plan to achieve a hierarchy of goals, accept input from others, and communicate all of that to key stakeholders. Students can then build on that skill set through project presentations (including plans and results), and role plays in communicating with potential stakeholders (potential funders, collaborators, managers). This may be accomplished within the context of research projects, or more broadly, within the context of leading projects and organizations. Fundamentally, when a
school teaches its students to develop and communicate a vision, they are teaching them to stay focused on the big picture, even while working on intricate details of a technical project. This is a valuable leadership skill that is central to the pillar of CC.

Second, we suggest engineering schools continuously encourage students to Adopt a Platform Mentality. We draw from literature on innovation to make a distinction between products and platforms\textsuperscript{13,14}. Products represent specific inventions that can be easily patented, licensed, and sold (e.g., Apple iPhone 6 or a specific medication), and they are more narrow in focus than platforms. In contrast, platforms take a bigger picture, systems view, and serve as the foundation for many types of new products. For example, the iOS is the platform for the iPhone, but can also be used as an operating system for multiple types of electronic devices (computer, TV, watch, tablet). Similarly the platform underlying a medication product may be a set of biotechnology processes that make mini-factories out of living cells. The importance of this distinction lies in the fact that platforms can have a far-reaching impact and influence developments of multiples types of products. Although both can have a relevant impact on society, a platform mentality encourages the leadership skill of staying focused on the big picture and the end result, reinforcing the first tenet, leading with vision, as described above.

Like the ERCs, engineering schools can integrate a systems focus into their classrooms and programs overall, encouraging this big picture focus. For example, a computer engineering professor could teach students to develop a protocol for a computer chip (platform) and then develop a specific type of hardware using that protocol (product). By participating actively in both types of projects, students could learn how and why to pursue a platform mentality. Taken a step further, students who present their findings and conclusions to the class or external partners
also develop their ability to articulate complex subjects in an audience-appropriate manner, which requires a focus on the big picture, rather than minute technical details.

This leads naturally into the third principle, which is *Adopting a Synthesis Mentality*. The biotechnology-medication platform example above illustrates the need to integrate skill sets from multiple disciplines (i.e., biology, medicine, engineering, and others) and the more students can learn to synthesize, the more well-rounded they become in terms of technical and leadership skills. Massachusetts Institute of Technology (MIT) is a prime example of this, as they evolved through two distinct ERCs over two decades, involving multiple types of engineers, medical doctors, and biologists to develop foundational platforms for a wide range of life-saving and quality-of-life-saving drugs\textsuperscript{21}. By integrating skills sets through synthesis, students are exposed to multiple areas of expertise, and from a leadership standpoint, this will help them learn to communicate and solve problems across boundaries. At its core, this means embracing an interdisciplinary approach, through which educators can instill the principle of synthesis across domains, and reinforce the need for both technical and leadership skills. This may occur at a program level by fostering partnerships with other departments or schools, and it may occur at a classroom level by encouraging cross-disciplinary class projects. For example, professors might assign a team project involving negotiation of the intellectual property rights of a new technology, in which engineering students are paired up with students in an entrepreneurship or management class. We provide more details on this interdisciplinary focus in the next pillar.

Finally, we emphasize the need to teach students to *Persist*. In contrast to short-term class projects, real-world innovation often takes years and involves many detours. Likewise, it involves long-term personal development in both technical and leadership realms. Engineering schools might reinforce these ideas through long-term portfolio development, which continues
throughout a student’s pursuit of a degree. Research assistantships, internships, or involving students in the work of professors across various departments will also prepare students to take a long-term view in their work. Professors rarely explain their research to students who are not involved in their research laboratories, but all students could benefit from observing the long-term process required for real-world innovation, including both technical and leadership skills used. It would also be useful for students to have exposure to the types of large scale interdisciplinary efforts popping up all over the country and world. For example, with a bill passed in 2015, Congress funded several new manufacturing centers, which should increase the rate of innovation in this important industry by bringing together researchers from both academia and industry, across disciplines.²² By exposing students to these types of endeavors, educators reveal the importance of persistence in innovation, in personal development, and in career advancement. Throughout long-term efforts, they also learn important leadership skills underlying the pillar of CC, including staying focused on big picture goals even in the midst of many intricate details.

In sum, CC pushes engineering schools to embrace a systems view, moving beyond a short-term, one-class-at-a-time, one-problem-at-a-time view. Adopting this strategic pillar in an engineering school, university leaders can foster in students an appreciation for and ability to think critically and strategically about the big picture in the innovation process and their own leadership role in that. Schools embracing CC also will encourage students to see the importance of communicating vision in a compelling way, and then contributing to engineering practice in a relevant, innovative and practical way. Such schools will foster both technical and leadership skills to better prepare graduates to be the technical leaders of the future.
**Boundary-Breaking Collaboration**

The second strategic pillar is Boundary-Breaking Collaboration (BBC). This involves sharing information and other resources across disciplinary and institutional lines, including industry, academia, and government. Many educational models try to foster collaboration skills by using student teamwork\(^{15}\), because this helps students learn from diverse perspectives and learn to work together as they will do in the real world. But the type of collaboration that is truly boundary-breaking (and therefore transformative) goes beyond simple class project teamwork.

The ERC Program promotes BBC through the design of research centers as hybrid, multi-institutional organizations. Typically, multiple universities and industry partners, and sometimes government agencies, are key partners who actively work together to design and implement complex research projects. Students are involved in every aspect of this, and often act as translators across these boundaries. This experience gives students a safe environment in which to learn to communicate well, work with different personalities and organizational cultures, and even learn about what motivates different people throughout a project. In addition to technical skills learned from people representing diverse disciplines and skill sets, these experiences give students invaluable experience in informal leadership roles. Some ERCs take this a step further, creating student project teams of engineers, scientists, business students, and perhaps even law students or graphic designers; these teams are charged with conducting collaborative projects that are part of coursework and relevant to departmental and university goals. We propose three specific prescriptions as a formula for engineering programs, even those that do not exist within a large-scale effort like an ERC, to implement the tenet of BBC. In contrast to CC, which
proposed specific educational experiences for students, BBC includes recommendations for broader, programmatic changes to engineering education programs.

The first principle is *Lead through Persuasion and Trust*. Any successful organizational change requires strong leadership commitment and careful communication. Before requiring a new level of collaboration, university leaders must role-model BBC themselves through their own partnerships, and communicate the goals of this type of collaboration to all in a way that fosters trust and motivation to embrace the changes. They must also learn how to speak the language of their collaborators, thereby demonstrating through word and action that they are a trusted partner in those endeavors.

Second, we propose that leaders *Create Interdependence*. This includes building organizational and programmatic structures that require collaboration across boundaries to achieve goals. For example, creating engineering classes that are cross-listed in both engineering and business, which require input from faculty in both schools, weaves the need to collaborate into the organizational fabric. We have seen some universities that do this in their communication or entrepreneurship courses. Alternatively, as part of a capstone requirement, engineering graduates could be required to gather input from a researcher in each engineering discipline (and even other non-engineering disciplines) for an integrative project. This would give them exposure to multiple disciplines while instilling the leadership skills of project management and communication skills. A similar requirement could be made to require students to reach out industry partners as part of an integrative project.

Third, we encourage engineering leaders to *Build Bridges across Boundaries* for students and faculty to utilize. This includes links with industry partners, government entities, other universities, and other disciplines (within and outside the engineering school). Borrowing a best
practice from ERCs, universities could designate this relationship-building as a responsibility for an external relations liaison, someone whose sole job it is to build these linkages from which students and faculty can benefit. We further detail this liaison role in the next pillar.

In summary, BBC goes beyond encouraging student teamwork, and opens up student horizons to more diverse perspectives, knowledge bases, and communication styles. By facilitating linkages with a diverse array of individuals, and building in requirements for students to leverage those linkages, we believe engineering schools can fully embrace a new paradigm that inherently instills leadership skills in conjunction with technical skills. By infusing more interdisciplinary interactions, we are not refuting the value of learning one’s own discipline very well. Instead, we are suggesting that a student can learn one’s own discipline, perhaps even better, when they have a well-rounded perspective and network of collaborators to invest in their (both technical and leadership) learning journey.

**Orchestrated Commercialization**

The third and final pillar of Organized Innovation, Orchestrated Commercialization (OC), means intentionally coordinating the process needed to move engineering research from idea inception throughout the technology commercialization pipeline. Building on the first two pillars, OC emphasizes the method by which engineering output is applied outside a research laboratory, through a full spectrum of commercialization activities. ERCs provide valuable exposure to these processes, which many students in traditional engineering programs do not get\(^\text{17}\). This may include skill-building for collaboration, but also motivating and enabling people to participate in a process that may be cumbersome, time-consuming, and associated with
uncertain rewards\textsuperscript{18,19}. OC also introduces students to the entrepreneurial and business aspects of innovation, which are strategic skills needed for all leaders, especially those overseeing technical projects.

The formula for implementing OC focuses at the program-level. By implementing three recommendations, leaders can increase the knowledge, ability, and motivation of students to engage in the full process of commercialization, thereby gaining technical and leadership skills required for an engineer in the twenty-first century workforce.

First, departmental and university leaders must \textit{Coordinate the Network}. A plethora of experts are required to successfully move an innovation through the pipeline from idea to application. For example, lawyers, venture capitalists, personnel from the office of technology transfer, business school professors and alumni, and serial entrepreneurs can all help move innovations beyond the research laboratory. Students and faculty can both benefit from exposure to these experts as they design their own projects. Furthermore, they learn about how to effectively navigate the innovation process and develop their own expertise in engaging in that process. Using the BBC \textit{Building Bridges} principle as a foundation (described above), leaders can build relationships with these experts, naming them as strategic partners of the engineering program, and partnering with them to expose students to the entire process of commercialization. Furthermore, we advocate for the appointment of a dedicated liaison to program partners. This person should have responsibility for building relationships, helping students and faculty work with the partners, and helping the partners work with the university. These partners should regularly interact with students and faculty through guest speaking, professional development workshops, and/or as consultants or collaborators on active research projects. One-on-one
student mentoring and/or faculty mentoring may be another way to build this network and leverage it for leadership and technical skill-building within engineering schools.

Second, we urge leaders to *Elevate Role Models*. By identifying engineers who have successfully launched commercialization and other entrepreneurial ventures, leaders can motivate students to develop their own skills, and open up their worldview to what is possible in their careers. These may be faculty members who are particularly good at bridging the gap between technical and leadership roles, or outside partners. Alumni of the program who have successfully commercialized their own work, or participated in any form of entrepreneurship by applying both leadership and technical skills may be particularly effective in capturing student attention for the importance of these activities. These individuals may be part of the coordinated network described above, but this focus on role models is a unique one for leaders to ensure they are communicating effectively about the importance of these activities, and how they position engineering students to lead as well.

Third, leaders should work with decision-makers in their university setting to *Revisit Incentives* for commercialization, and more broadly, building the leadership and technical skills required for commercialization success. Traditional university departments incentivize students for excelling in purely technical engineering coursework. But in implementing the principles described this far, leaders may need to create incentive structures, such as class credit, degree credit, extra credit, honors status, or other distinctions that motivate students to develop their leadership skills in addition to technical skills. Contests that reward students for the best business start-up and/or product idea may also work; University of Southern California’s Stevens Center for Innovation has successfully adopted a program like this. There are career rewards awaiting students who focus on building these skill sets, which may be less immediate or salient than
salaries in a student’s first technical job, but it behooves leaders to communicate the expanded possibilities to students who make the effort to get the most out of their enhanced Organized Innovation-inspired educational experiences. Faculty will likely also need to be incentivized for participating in such activities.

A key aspect of OC is that it exposes engineering students to the business world and importance commercialization processes that they are most likely to engage in throughout their careers. This includes effectively navigating the full commercialization process, but also effectively interfacing with diverse individuals and organizations. Thus, schools can give students a competitive advantage as they graduate and enter the workforce, and students who have such exposure are likely the ones who will go on to have satisfying, creative careers that also seek to confidently apply their knowledge and experiences.

Section 5: Conclusion

We have described the highly successful NSF ERC program as a model for developing engineering leaders. However, the Organized Innovation Model for Education can be implemented at any engineering or other science-based department, not just those participating in a large-scale collaborative research center. By channeling the curiosity of engineering students toward the big picture with research that can have societal impact (CC), fostering cooperation across traditional boundaries (BBC), and exposing students to effective orchestration of the commercialization process (OC), engineering programs can put students at the center of a high-powered, inspiring innovation engine. Of course, any formal leadership training is also valuable, and we advocate for continued development of those programs, and expanding their reach to
more students. But even for universities without access to those programs, young engineers-in-training can benefit from actively learning both technical and leadership skills through the principles described here, which are increasingly integral to success in the twenty-first century economy.

We advocate all engineering schools consider how to implement these practices into their existing curricula as they prepare for the future. Faculty who are currently in engineering management or engineering leadership programs may lead the way, and may find these principles useful in enhancing the effectiveness of their existing programs or creating new programs. When possible, we encourage university leaders, including engineering education deans and professors, to explore creating or joining some type of a collaborative research center, modeled after the ERCs and the principles of Organized Innovation24, and we urge industry leaders to participate in these centers—boosting their own competitiveness even as they support research and education activities. The NSF ERC Program has published a Best Practice Manual, which may also be useful to any engineering program considering implementing any aspect of the tenets described here25.

In conclusion, the Organized Innovation perspective offers a high-impact educational model with the potential to build both technical and leadership skills in the next generation of engineers. Students graduating from such programs will not only be better prepared for satisfying, successful careers, but better equipped to help the nation and the world overall. They will have increased capabilities to generate and commercialize the kinds of technology breakthroughs vital to good jobs and a prosperous future for all.
Bibliography


