Developing Engineering Leaders: An Organized Innovation Approach to Engineering Education

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Abstract: In addition to providing technical expertise in their respective fields, engineers are increasingly assuming leadership roles in academia, industry, government, and even non-profit organizations. We draw from lessons learned in our decade-long study of the National Science Foundation Engineering Research Center program to provide both a theoretical framework, the Organized Innovation Model for Education, and tangible recommendations to educators, engineering managers, and anyone else interested in developing highly skilled engineers who are also excellent leaders. The model addresses a long-lamented need for systematic ways to integrate leadership development into technical curriculum and skill-building programs.

Keywords: Commercialization, Engineering Management Development, Engineering Research Centers, Higher Education, Innovation, Leadership Development, Leadership Skills, National Science Foundation

EMJ Focus Areas: Engineering Management Profession, Leadership

How do we transform engineering students into leaders? This is a dilemma many scholars are attempting to answer as engineers continue to be key contributors in the ongoing, high-stakes innovation race for global economic competitiveness (Currall, Frauenheim, Perry, & Hunter, 2014; Daniels, 2009; Eschenbach, 2013; Farr & Brazil, 2009; Kern, 2002; Stephenson, 2002; Weiss & Adams, 2011). In this article, 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 based on our decade-long study of the National Science Foundation (NSF)-funded Engineering Research Center (ERC) program (cf. Currall et al., 2014; Hunter, Perry, & Currall, 2011; Perry, Currall, & Stuart, 2007; Perry, Hunter, & Currall, 2016), 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 and previous empirical work 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 multidisciplinary, multi-institutional university research centers. In this final section, we provide specific recommendations for educators, university leaders, engineering managers, and policy makers on how leadership development might be integrated into existing education systems to produce a better prepared, leadership-ready, engineering workforce.

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 (Daniels, 2009; Eschenbach, 2013; Farr & Brazil, 2009). 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. Still, some engineers seem naturally suited for leadership roles. For technical leadership positions, in particular, both skillsets are required, but overemphasis on technical training remains (Farr & Brazil, 2009; Weiss & Adams, 2011). The question for educators and managers wishing to develop the next generation of leaders 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 (Eschenbach, 2013; Kotnour & Farr, 2005). Offerings range from voluntary workshops offerings (e.g., Brigham Young University’s Weidman Center for Global Leadership) to full undergraduate or graduate degree programs (e.g., Duke University’s Master of Engineering Management Program). In some instances, partnerships are created with other colleges which have expertise in leadership issues, such as business. In almost all cases, students opt in, which creates a self-selection bias. That is, those who are naturally inclined toward a leadership skill set are the most likely consumers of such offerings. Thus, the problem remains of how to help traditional engineers develop leadership skills while they also learn the technical skills of 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 (Currall et al., 2014; Daniels, 2009; Friedman & Mandelbaum, 2011; Perry, Currall, Frauenheim, & Hunter, 2015; Washington Post, 2014). Tech-savvy leaders are needed to manage these complex innovation creation efforts, which increasingly require more inter-disciplinary and inter-institutional collaboration (Hunter et al., 2011; Kern, 2002; Stephenson, 2002). We propose that no one is better suited to
fill those roles than engineers who have a complex technical skill set and a leadership skill set (Farr & Brazil, 2009; Weiss & Adams, 2011). But to provide a pipeline of such uniquely positioned leaders, a revised leadership development model is needed that reaches all engineering students.

Evidence From Engineering Research Centers
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 (Perry et al., 2007). The university-based ERC program began in 1985 with a mission to strengthen the competitiveness of U.S. 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 (Engineering Research Centers, 2008; Roessner, Manrique, & Park, 2010). Examples include advanced mobile phone platforms, breakthroughs in electronics miniaturization, foundational techniques in biotechnology, and even development of an artificial retina that restores sight to the blind (Currall et al., 2014).

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 courses and degree programs more systems-focused (Engineering Research Centers, 2008). Students who are educated within an ERC are better prepared, both technically and interpersonally. As shown in Exhibit 1 (Currall et al., 2014; Engineering Research Centers, 2008), nearly nine in 10 company supervisors rate former ERC students as better prepared to work in industry than equivalent hires without ERC experience. Nearly 75% of those supervisors also report employees with ERC experience are better able to develop technology. In addition, our interviews with ERC program personnel and industry partners revealed 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.

What is it about ERCs that make them role models for how to create advanced engineering educational experiences? Perhaps surprisingly, we did not find any explicit leadership courses in our examination of ERCs. Instead, they provide continuous, informal, hands-on educational experiences that inherently teach leadership skills. Farr and Brazil (2009) extol the importance of this real-world experience for building a strong foundation of leadership skills early in one’s career. As part of these experiences, many ERC researchers and leaders we interviewed 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

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**Exhibit 1.** Performance of ERC Graduates With Non-ERC Hires: Comparisons by Member Firms
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 in traditional academic departments, and perhaps even in the workplace, as leaders aim to equip the next generation of engineering managers.

In the next section, we briefly describe the research methodology we employed over a decade of examining ERCs. We used this empirical foundation, which was a quantitative and qualitative research effort, to formulate the conceptual recommendations in this article. 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 an ERC-like organizational structure.

**Research Methodology**

Methodological rigor was maximized in our study of ERCs 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 (Currall, Hammer, Baggett, & Doniger, 1999). Combining these types of data adds balance (McCall & Bobko, 1990) and an extra level of contextual detail and interpretability to the results of the study (Conger, 1998). This practice increases the extent of discovery, making research more methodologically sound. (For full details on our data collection and empirical analyses, see our previously published empirical work: Currall et al., 2014; Hunter et al., 2011; Perry et al., 2016).

To begin, we conducted semi-structured interviews of ERC representatives (students, faculty members, 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 11 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 2,300 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 program office. They contained information on technology transfer outputs, personnel, students, education milestones, strategic plans, and considerable other information about the current status of each ERC. We followed up approximately five years later to conduct 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 (Corley, Boardman, & Bozeman, 2006; Perry et al., 2016; Roach & Sauermann, 2010). Our program of research aims to address this overarching question, and the present conceptual article tackles this question from the specific perspective of leadership development among a highly technical workforce.

**Recommendations: The Organized Innovation Model For Education**

In this section, we describe the proposed Organized Innovation Model for Education, which contains three strategic pillars: Channeled Curiosity, Boundary Breaking Collaboration, and Orchestrated Commercialization (built on propositions in Currall et al., 2014; see Exhibit 2). These are guiding tenets that can be adopted by any university, academic unit, or organization that wishes to better prepare science or engineering graduates to be leaders in the workplace. Within each strategic pillar, we provide specific prescriptions for implementation in engineering programs.

**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 (Finelli, Daly, & Richardson, 2014). 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 (Sabat, Morgan, Perry, & Wang, 2015). Through these experiences, students collaborate with team members, manage projects, and communicate results to members of the class, which enhance leadership skills even while reinforcing technical concepts (Beard, 2010; Finelli et al., 2014).

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 (Engineering Research Centers, 2008). Thus, 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 should teach students to 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 (Anantatmula, 2010; Currall et al., 2014; Hunter et al., 2011; Miller & Cardinal, 1994; Perry et al., 2016). Recent research also suggests that engineering management has made a significant shift toward a more strategic
orientation in response to globalization and other economic trends (Weiss & Adams, 2011). Engineering programs can teach students the fundamental principles of strategic planning, which include writing mission and vision statements, making a plan to achieve a hierarchy of goals, accepting input from others, and communicating 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 captured in the highly effective transformational leadership style (Dixon, 2009; Hirtz, Murray, & Riordan, 2007; Laglera, Collado, & Montes de Oca, 2013), and it is central to the pillar of CC.

Second, we suggest engineering schools encourage students to *Adopt a Platform Mentality*. We draw from literature on innovation to make a distinction between products and platforms (Bridgwater, 2015; Currall et al., 2014; Frattini, Bianchi, De Massis, & Sikimic, 2014). Products represent specific inventions that can be easily patented, licensed, and sold (e.g., Apple iPhone 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 one platform underlying many medication products 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 multiple types of products. Although both can have a relevant impact on society, a platform mentality encourages the visionary leadership skills of staying focused on the big picture and the end result, reinforcing the first tenet, leading strategically with vision (Dixon, 2009).

Like 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 to different audiences, which requires a focus on the big picture, rather than on 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 (Eschenbach, 2013). 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 (Currall et al., 2014). 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 law 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 expose students to the need to take a long-term view in their work. Professors rarely explain their research to students who are not involved in their laboratories, but all students could benefit from observing the long-term process required for real-world innovation, including the technical and leadership skills used to manage projects over time.

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 (Currall, Frauenheim, Perry, & Hunter, 2015). By exposing students to these types of endeavors, educators reveal the importance of persistence in innovation, in personal development, and in career advancement. Through 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 role in it. Schools embracing CC also will encourage students to see the importance of communicating in a compelling way, and then contributing to engineering practice in a relevant, innovative, and practical way. Such schools will inherently foster both technical and leadership skills to better prepare graduates to be the technical leaders of the future, without adding any explicit leadership coursework or programs.

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 those separating industry, academia, and government. Many educational models try to foster collaboration skills by using student teamwork (Gatchell, Ankenman, Hirsch, Goodman, & Brown, 2014), 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 projects.

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, with 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 to implement the tenet of BBC, even those that do not exist within a larger-scale effort like an ERC. In contrast to CC, which only proposed specific educational experiences for students, BBC also entails 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 (Manz, Keating, & Donnellon, 1990). 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 (Daniels, 2009; Kern, 2002; Laglera et al., 2013). 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. This type of exposure has been emphasized as invaluable by leading engineering management scholars because it fosters a broader understanding of the big picture of any problem faced (i.e., Eschenbach, 2013; Farr & Brazil, 2009). Engineering programs could offer this type of exposure by, for example, creating engineering classes that are cross-listed in both engineering and business, which require input from faculty in both schools and weave the need to collaborate into the organizational fabric. Alternatively, as part of a capstone requirement, engineering students 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 that students reach out to 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 of the engineering school). Borrowing a best practice from ERCs, universities could designate an external relations liaison, someone whose sole job it is to build these linkages from which students and faculty can benefit. We further describe this liaison role in the next pillar.

In summary, BBC goes beyond encouraging student teamwork, and opens up student horizons to more diverse perspectives, disciplinary 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 students supplement the knowledge of their chosen discipline with the wisdom of a well-rounded perspective and network of collaborators who can advance their learning journey, from both a technical and leadership perspective.

**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 (Dietz & Bozeman, 2005). 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 (Lam, 2011; Lam & Lambermont-Ford, 2010). 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 (Daniels, 2009; Eschenbach, 2013; Farr & Brazil, 2009; Stephenson, 2002; Weiss & Adams, 2011).

The formula for implementing OC focuses primarily 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 21st century workforce. First, departmental and university leaders must *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 *Building Bridges* principle as a foundation, leaders can build relationships with these experts, naming them as strategic partners of the program, thereby exposing students to the entire process of commercialization.

Furthermore, as suggested in the BBC pillar, 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 and/or faculty coaching 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 capture students’ attention regarding the importance of these activities. These individuals may be part of the coordinated network described above. But besides merely including them in the learning process, it is important to shine a spotlight on role models—both to highlight the significance of OC activities and to show students real-life examples of engineering leaders.

Third, leaders should work with decision-makers in their university to *Revisit Incentives* for commercialization, and more broadly, building the leadership and technical skills required for commercialization success. Although many of our suggestions do not require explicit leadership program participation, traditional university incentives to students for excelling in purely technical engineering coursework may benefit from expansion. That is, in implementing the principles described thus 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, or at least to go above and beyond in the activities described. 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 (Tsai, 2015). 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 to participate in such activities, including in the enhancement of existing courses to include these additional experiences for students.

A key aspect of OC is that it exposes engineering students to the business world and important commercialization processes in which they are most likely to engage 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 and successful careers.

**Implications For Engineering Managers**

The recommendations described here have the potential to finally transform engineering education into a system that better
prepares capable leaders—a need scholars and other experts have lamented for decades (i.e., Farr & Brazil, 2009; National Academies, 2005). Although we focused primarily on transforming traditional academic programs in universities, engineering managers can also use the model to integrate leadership development into their existing programs for the next generation of leaders in the workplace. Many of our recommendations involve a university reaching out to industry to build connections, but engineering managers can also benefit by reaching into universities to build connections. Such partnerships have been highly fruitful for industry, in addition to students and universities, as showcased by the success of the ERC program (Currall et al., 2014). Alternatively, engineering leaders might implement some of these recommendations within their own organization. For instance, by purposefully designing interdisciplinary project teams and/or building relationships with diverse organizations, and giving both junior and senior engineers key strategic roles in those interactions, engineering leaders may enable more CC-, BBC-, and OC-inspired experiences to develop future leaders. The principles we propose are really about a shifting mindset and designing an environment with opportunities to capitalize on that mindset shift, meanwhile providing every - day, real-world leadership development opportunities for more engineers, even when they would not self-select into a leadership development program.

**Conclusion**

The need for leadership skills in driving team productivity, building healthy organizational culture, fostering employee retention, and contributing to organizational effectiveness is supported by research across disciplines, including in engineering management (e.g., Ammeter & Dukerich, 2002; Anantatmula, 2016; Currall et al., 2014; Hirtz et al., 2007; Hunter et al., 2011; Laglera et al., 2013; Levin, 1993; Perry et al., 2016). Despite this widespread agreement, engineering programs still lack a systematic method for exposing all students to leadership development (Farr & Brazil, 2009). We have described the NSF ERC program as a model for developing engineering leaders, based on its success in educating students, benefitting industry, government, and academic partners, and making an economic impact. But unlike the large-scale, institutionalized ERC model, the Organized Innovation Model for Education can be implemented at any engineering or other science-based department, or in organizations. Although the entire model (i.e., every recommendation) may be resource-intensive to implement all at once, it includes many smaller steps and principles that can be easily integrated into existing programs and curriculum, at the classroom or the program level. By channeling curiosity toward big-picture problem solving 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. Our recommendations mean that implicit leadership training can be integrated and made available to all engineers, not just those at institutions with formal leadership training, or those that self-select into extracurricular activities.

We advocate that all engineering schools, and organizations facing the challenge of developing their future leaders, consider how to implement these practices into their existing programs as they prepare for the future. Faculty who are currently in engineering management or engineering leadership programs may lead the way to enhance the effectiveness of their existing programs or create new programs by implementing some of our suggestions. When possible, we encourage university and industry leaders to explore creating or joining a collaborative research center, which can exist on any scale (see National Science Foundation Engineering Research Center Program, 2012 for best practices). But even individual faculty members can take steps toward integrating more implicit leadership development in the courses they teach. For example, an appropriate first step may be to introduce a new multidisciplinary project (incorporating one or more of the suggestions made here) into a traditional engineering class. Success from smaller efforts will provide evidence to program leaders about the potential of larger initiatives. Future research that assesses the effectiveness of these practices as they are implemented in traditional engineering programs and workplaces would be highly beneficial to educators, engineering managers, and the engineering education field as a whole, in efforts to develop more evidence-based, tailored recommendations.

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. Engineers 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 lead others in generating the kinds of innovations vital to good jobs and a prosperous future for all.

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Comprehensive review of leadership and organizational dynamics.


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