Why the Hard Science of Engineering is No Longer Enough to Meet the 21st Century Challenges

by

Richard K. Miller

*"It's in Apple's DNA that technology alone is not enough — **it's technology married with liberal arts, married with the humanities, that yields us the results that make our heart sing**..."*
STEVE JOBS (UNVEILING THE IPAD2), MARCH 2011[1]

EXECUTIVE SUMMARY. It has been more than fifty years since the engineering curriculum in the U.S. has changed significantly. In the 1950s, a strong emphasis on applied science and mathematics was introduced and since then it has become the heart of the engineering curriculum. However, much has changed in the last fifty years. The world has become much more complex and the Grand Challenges[2] we face now involve human behavior as much as they do technology. It is time to rebalance the engineering curriculum again, restoring some of the emphasis on professional skills[3]. This paper examines the reasons why now is the time to undertake such an ambitious project and what this will entail.

HISTORICAL BACKGROUND. The last major rebalancing of engineering education occurred after 1955 when the Grinter Report[4] marked a "sea change" in engineering education. This report established a sudden comprehensive shift in the undergraduate curriculum toward the hard sciences and mathematics. Calculus and physics became requirements for all engineering majors and faculty were expected to have a Ph.D. and participate in original research published in archival journals—just like their counterparts across campus in the natural sciences. In order to shift the balance in the curriculum, a shift in faculty credentials and interests was necessary, and the more ambiguous and less analytical aspects of the practice of engineering were no longer dominant. This major rebalancing was achieved over a few decades. Since then, the culture in academia (driven largely by the interests of the faculty) has continued to grow in the direction of applied sciences, with the underlying belief that the most important new developments in engineering will always flow directly from discoveries in the basic sciences. From an educational viewpoint, the foundational belief is that knowing more advanced science and math is inherently beneficial and increasing specialization is the key to making more important contributions as well as career success.

Without question, the rebalancing of the 1950s played an important role in propelling the nation to success in the Cold War and in building and sustaining the world's most powerful economy and standard of living. The role of engineering in creating the greatest technological achievements of the twentieth century is documented in a recent book[5] published by the National Academy of Engineering.

Emergence of complex Grand Challenges. However, the world has changed in many ways in the last half century, while our educational paradigm for engineering has not. For example, the technical challenges we face today are inherently more complex and global[2]. They transcend academic

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1 Carmody, Tim, *Without Jobs as CEO, who speaks for the arts at Apple?,* Business, ***Wired***, August 29, 2011.
2 The **National Academy of Engineering** identified 14 Grand Challenges for the 21st century that cluster in four areas: Sustainability, Security, Health, and the Joy of Living. http://www.engineeringchallenges.org/
3 Professional skills are sometimes referred to within engineering schools as "soft skills." They generally do not depend on an understanding of science or math. However, they have proven much more difficult to define and teach than the more traditional subjects. In that sense, the term "soft skills" may be a misnomer.
4 *Summary of the Report on Evaluation of Engineering Education*, **Journal of Engineering Education**, September 1955, pp. 25-60.
5 Constable, George, and Somerville, Bob, *A Century of Innovation: Twenty Engineering Achievements that Transformed Our Lives*, National Academies Press, 2003.

disciplines, political boundaries, and time zones. Challenges such as global security, sustainability, health, and enhancing the quality of life in an age of exploding world population will require more than new technologies or science. They will require more comprehensive and complete situational diagnoses, involving interdisciplinary understanding of the root causes and the consequences of any new technology introduced into the world. They will require global systems planning and analysis, involving social, economic, political, and even religious factors to obtain desired changes in human behavior on both local and global scales[6].

Many of the challenges of today involve unintended consequences of the technologies developed in the last century. These consequences can often be traced to original conceptualizations that were too narrow or failed to include these "non-technical" dimensions to the problem in the first place. Those technologies often arose from analyses that ignored or underestimated the human behavioral aspects of the problem. To avoid this in the future will require multidisciplinary teams working together to diagnose problems and design solutions that result in fewer unintended consequences. The stakes are very high and are increasing with each generation, in part due to the increasing population, and in part due to the increasing power of (and relentless advances in) technology which, generally, enables a smaller and smaller number of people in each generation to affect the lives of a larger and larger number of others, both intentionally and unintentionally, and both for the better and for the worse.

The successful multidisciplinary teams needed to address these Grand Challenges must, of course, include members with advanced knowledge of the natural sciences and mathematics. The importance of continued advances in these fields has not and will not decline. It is implicit that we will continue to need experts and innovators in the pure and applied sciences and in mathematics, which has become the primary focus within our universities.

However, unless these advances are motivated by and integrated with equally sophisticated understanding of the complex human dimensions of the problems we face, they are unlikely to succeed. Furthermore, the need for synthesizers and integrators leading such teams is of fundamental importance. Like the conductor of the orchestra rather than a soloist, these multidisciplinary leaders are needed to shape the overall effort and produce an effective integrated result[7].

These special integrative skills are more closely related to the field of design than to analysis—which had been the hallmark of engineers before the Grinter report. Now that fewer engineers are prepared with these skills, the job of leading such teams in formulating and solving complex problems of this type often falls on others with much less preparation in the natural sciences—like politicians and business leaders. As a result, the critical need today for new insights that bridge technical disciplines and human behavior too rarely involves engineers. The academic field of engineering today does not adequately value broad thinking, synthesis, teamwork and consensus building, entrepreneurial mindset, and creative design as much as it does advanced analysis and new science. These "professional" skills were perhaps inadvertently de-emphasized in the curricular rebalancing a half-century ago.

Since much of the complexity of the Grand Challenges is the result of the inherent coupling between the technical and the human/social dimensions of the problems we face, the importance of the humanities and social sciences in the engineering curriculum must increase. In this context, a recent report by the American Academy of Arts & Sciences[8] lays out a compelling case for the humanities and social sciences in any education today. They conclude that "the humanities and social sciences are the heart of the matter, the keeper of the republic—a source of national memory and civic vigor, cultural understanding

[6] National Academy of Engineering, The Engineer of 2020: Visions of Engineering in the New Century, 2004, National Academies Press, Washington, DC.

[7] Nobel Prize winner Murray Gellman, in addressing this concern, identified what he called the need to take a "crude look at the whole" (CLAW). "*People must therefore get away from the idea that serious work is restricted to beating to death a well-defined problem in a narrow discipline, while broadly integrative thinking is relegated to cocktail parties. In academic life, bureaucracies, and elsewhere the task of integration is insufficiently respected*." (The Quark and the Jaguar: Adventures in the Simple and the Complex, 1995, p. 346)

[8] **AAAS**, *The Heart of the Matter: The Humanities and Social Sciences for a Vibrant, Competitive, and Secure Nation*, Cambridge, MA, 2013.

and communication, individual fulfillment and the ideas we hold in common." It is these subjects that not only provide the essential insights for addressing the Grand Challenges, but also provide the nourishment for human understanding and wellbeing beyond the physical and financial. It is time to give our engineering students more opportunity to integrate them into their world.

> *"All of these problems at the end of the day are human problems," he said. "I think that that's one of the core insights that we try to apply to developing Facebook. What [people are] really interested in is what's going on with the people they care about. It's all about giving people the tools and controls that they need to be comfortable sharing the information that they want. If you do that, you create a very valuable service. **It's as much psychology and sociology as it is technology**."*
> MARK ZUCKERBERG (SPEAKING AT BYU)[9]

The rise in global competition. In about 1920, global human population reached one billion for the first time in history. Today, less than 100 years later, it is slightly above seven billion, and we are expecting about nine billion by mid-century. Every human society is likely to experience the effects of this sea change in population. It will create increased demand for clean water, food, energy, security, education, transportation, communication, and every other dimension to civilized existence. We have already seen major shifts in the geopolitical balance and more shifts are certain to follow.

In just the last few decades the BRIC[10] countries have experienced a rapidly rising middle class. One of the primary interests of the middle class is education for their children. As a result, each of these countries is currently involved in massive investment in increasing access to higher education. For example, in India alone, several thousand new engineering colleges have been created in the last decade, and China has been building entire new universities at a fast pace for the past decade. As a result, the world's largest airport is now in China. GE has now located the majority of its R&D personnel outside of the United States. China has now replaced the United States as the world's number one high-technology exporter. Eight of the ten global companies with the largest R&D budgets have established R&D facilities in China, India, or both. China has a $196 billion positive trade balance, while the United States balance is negative $379 billion. During a recent period in which two high rise buildings were under construction in Los Angeles, over 5,000 were built in Shanghai. The world is changing rapidly and the role of the U.S. is destined to become less dominant in all areas[11].

These emerging nations are looking forward with an attitude that they will do whatever it takes to build an innovation-driven economy. As a result, of the nearly 500 universities that have visited Olin College in the last five years for the purpose of gaining insight into how to produce engineering innovators, 70% of them are from abroad. These nations are very serious about making investments in education that will catapult them into a leadership role in the innovation economy. They implicitly assume that change and improvement are needed, and they are willing to make substantial investments to initiate it. In contrast, many American universities are relatively complacent. As a wise mentor once told me: "there is no more powerful force for conservatism than having something to conserve." America is still widely regarded as the world leader in higher education, so we have a LOT to conserve. But if we remain flat footed while the rest of the world races ahead, they will eventually over-take us.

Decline in student interest in STEM subjects. Another major change of equal importance that has occurred in the last fifty years is the decline in student interest in STEM fields and the decline in quality and rigor of their preparation in K-12 in these fields. Fewer than 5% of the bachelors degrees awarded across America last year went to students who majored in any kind of engineering at any university in the

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9 Larson, Chase, *Mark Zuckerberg speaks at BYU, calls Facebook as much about psychology and sociology as it is technology,"* **Deseret News**, March 25, 2011.

10 Brazil, India, Russia, and China

11 National Academy of Engineering, **Rising Above the Gathering Storm, Revisited: Rapidly Approaching Category 5**, National Academies Press, Washington, DC, 2005, p. 7.

nation[12]. Less than half of all incoming students who choose engineering as their major will graduate in engineering. And many of the students who drop out of engineering have higher grades than those who stay[13]—so it is not a lack of skill or intelligence that drives students out of engineering. Students today are highly motivated to tackle the Grand Challenges of our age, but they don't see the narrow study of the fundamentals of natural science and math as the key to these problems[14]. They see the problems as more human than scientific. They are looking for a way to make a positive difference in the world—in the lives of people. They don't often see the study of engineering science and math as being directly related to the problems they see or care about.

This disconnect is frustrating, even heartbreaking. It too often leads to disillusionment and abandoning the field altogether. In the current generation of young college graduates, the problem of finding their "calling" seems separated from their college degree more than in previous generations. Too many students graduate from college only to return home to think about what they want to do with their life. To a degree that is much higher than previous generations, they postpone marriage and family, struggle with identity and purpose, and seem overwhelmed with the complexity and frustrations in life.

Emergence of extracurricular competitions that inspire students. A few bright spots that have emerged in the last few decades might offer some insight into how to improve the situation. In the last decade, more K-12 students have encountered robotics than ever in the past. The excitement of team competitions that parallel those in traditional athletics has been brought to an increasing number of schools, largely through the efforts of Dean Kamen and Professor Woodie Flowers (with support from John Abele and others in industry) through the FIRST organization[15]. The impact of student experiences in actually making and competing with complicated robotic systems while in high school is undeniable. It is clearly capable of transforming lives and leaving students with a sense of empowerment and intrinsic motivation to study STEM subjects.

Another example is provided by the large number of K-12 students today who discover the ability to create their own computer code or an "app" for their smart phone. The experience of creating something that works, something that is valued by peers, and something that can be shared broadly with others is similarly transformative for many students. It can also result in a sense of empowerment and intrinsic motivation in computer science and math. A recent example of this type of student engagement is provided by code.org and its "hour of code" program[16].

It is hard to avoid the observation that these two recent trends are inherently ***experiential***, involve ***making*** things (rather than learning about things), and lie outside the traditional school curriculum. They require a complex number of non-technical skills including creativity and self-expression, taking the initiative to learn independently (since these topics are not part of the traditional curriculum), collaboration with others, perseverance and determination to succeed (now sometimes referred to as "grit"), and communication—including advocacy—with others. The power of these experiential learning opportunities to address many of the major concerns in education is hard to overlook. It is also tragic that they had to be developed outside the school curriculum[17]. The impact on students often extends beyond their knowledge and abilities, and includes a sense of empowerment, purpose, and direction in life.

Similar experiential learning opportunities are transformational during the college years, too. These include largely extra-curricular activities like the SAE Mini Baja race car competition[18], the ASME Human-

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[12] National Science Board, *Science and Engineering Indicators*, 2014.
[13] This is especially true of those who are women.
[14] Wadwa, Vivek, "*Students may resist geek studies. But they'll flock in for the opportunity to change the world.",* The Grand Challenge for Science and Math, **BusinessWeek**, March 9, 2009.
[15] www.usfirst.org
[16] www.code.org
[17] The widespread emphasis on standardized testing creates little incentive or opportunity for educational experimentation, although some non-traditional schools (such as High Tech High School in San Diego—and a growing number of others) are successfully pioneering a very experiential learning environment that provides nearly everything described in this paragraph.
[18] www.bajasae.net

Powered Vehicle competition[19], numerous computer "hackathons," entrepreneurial and business plan competitions, even some experiences in community service, music, athletics, and philanthropy, such a Toastmasters[20]. Students who find such opportunities and can successfully integrate them into their lives very often have better outcomes, educationally and in careers.

In addition, it is well known that students who complete a program with a required corporate internship have consistently better outcomes than those who do not. Corporate internships provide a well known example of what can happen if the engineering curriculum embraces the development of professional skills rather than ignores it. Students who graduate with an internship experience have a more realistic understanding of the context of engineering, and generally receive more and better career opportunities. Many companies give preference to candidates for employment that have internship experience and some companies restrict their recruiting efforts to students that have completed an internship within their company.

It is glaring that the missing professional skills in the preparation of engineers may be traced to the last rebalancing of engineering education, while many of the problems with student motivation and achievement in education today also appear to be related to the absence of these same contextual experiences that lead to enhanced professional skills.

The Internet and the shift from the "knowledge economy" to the "maker economy." One final observation about the changes in the last fifty years may have a bearing on this issue. Before the Internet age, knowledge was much harder to come by. Just finding the facts was often a time-consuming chore involving books, libraries, and consultation with "experts." An important goal of education then was to produce experts who were recognized for their specialized knowledge of the facts. This expertise often translated into a professional career with financial success. Just knowing things was often intrinsically valuable and respected. (The popular TV game ***Jeopardy!*** epitomizes the implicit value our society has historically placed on "knowing things.")

But after the widespread establishment of the Internet (and powerful free search engines like Google), finding facts has become immensely easier and cheaper. The intrinsic value of knowing things has declined drastically—and permanently. To a large extent today, it matters much less what you know than it does ***what you can do*** with what you know.

Learning to make things is inherently experiential, as compared to learning about things, which is much more cerebral. Those who work in the arts have always understood this. The arts have long focused on self-expression, design and studio "thinking," and pedagogies that involve long hours of practice and emotional engagement—like recitals and concerts. Mastery, rather than knowledge, is the primary goal of the arts. In the arts, it matters as much or more ***how*** you say or do things than it does ***what*** you say or do. Technic is the hallmark of artisanship, not knowledge alone.

As a result of the Internet revolution, higher education is beginning to shift. MOOCs have emerged to provide widespread access to high quality educational content at very low cost. The old pedagogical paradigm of the expert professor as "sage on the stage" delivering content to rows and rows of quiet students who take notes and prepare to demonstrate knowledge on tests is beginning to shift. Now, we see the emergence of more experiential learning in the ***mainstream*** of higher education. The sage on the stage is increasingly being replaced by the professor in the role of coach, as "guide on the side," with students now arranged around tables in small groups working together during class on a "maker" project. The room is no longer quiet, and the students are more personally engaged in their learning, with public speaking and presentation a common expectation.

As a result, professional skills are becoming much more important in this new "maker university" format, taking center-stage as students must learn to collaborate and produce results together as they develop mastery. More and more, the focus of educational topics in this approach involves complexity, ambiguity,

[19] www.asme.org/events/competitions/human-powered-vehicle-challenge-(hpvc)
[20] www.toastmasters.org

diagnosis, judgment, and human behavior, not simply mathematical answers or scientific facts. In the maker approach, the percentage of questions that have unique "correct" answers is declining. Judgment is increasing, and the skill of consensus building is becoming a prerequisite. In the university, as in industry today, students must learn to work productively with teams of others who have a different perspective or worldview. As a result, the ability to work effectively in teams and to assume a leadership role when needed has become much more common and important in the last fifty years, mirroring a shift in the organization of labor in the workplace during this period.

THE TIME HAS COME FOR ANOTHER REBALANCING OF UNDERGRADUATE ENGINEERING EDUCATION. For the first time in more than fifty years, the time has come to significantly "rebalance" engineering education. No amount of doubling down on hard sciences and math will provide the professional skills that are needed now. The relative emphasis between hard sciences and professional skills in the degree requirements for engineering graduates must change to address the changing needs of our times. When corrected, there will be more required activities for students that involve "maker" projects, and fewer that involve learning just-in-case knowledge about topics that are never actually used. Teaching students how to learn independently, how to improvise in the face of the unexpected, and how to master the skills needed to make an impact will be more important than relentlessly trying to increase the scope and number of new scientific topics that cannot be covered in depth. The many extracurricular projects that today succeed in inspiring and empowering students—often in spite of, not because of our curriculum—need to be moved into the core curriculum. This can and is being done with success in some programs already. The result will be no less than a revolution in engineering education.

While our focus is on engineering education, it is important to recognize that a similar revolution is needed more generally throughout STEM education, and perhaps all of higher education.

> *"Innovation is not simply a technical matter but rather one of understanding how people and societies work, what they need and want.* ***America will not dominate the 21st century by making cheaper computer chips but instead by constantly reimagining how computers and other new technologies interact with human beings****."*
>
> FAREED ZAKARIA[21]

WHAT DO WE MEAN BY PROFESSIONAL SKILLS? In order to move forward with any large-scale movement like this, it is necessary to answer a number of important questions. These begin with a more detailed discussion of what we mean by professional (or soft) skills.

In recent years, many employers have complained about the need for more attention to professional skills in new engineering graduates. The list of concerns almost always focuses on non-technical abilities or "people skills" that represent attitudes, behaviors, skills, and motivations and not just knowledge. A precise and unambiguous description of these dimensions to the abilities of engineers is very hard to find, although many recurrent themes are apparent.

For example, the **ABET** accreditation criteria for all engineering programs (Criterion 3 Student Outcomes, (a)-(k)[22]) contains 13 requirements for an accredited engineering degree. Six of these relate to professional skills rather than the use of the hard sciences. The professional skills they seek are described as follows:

- (d) an ability to function on a multidisciplinary team
- (f) an understanding of professional and ethical responsibility
- (g) an ability to communicate effectively

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[21] Zakaria, Fareed, *Why America's obsession with STEM education is dangerous,* **The Washington Pos**t, March 26, 2015.

[22] http://www.abet.org/wp-content/uploads/2015/04/eac-criteria-2013-2014.pdf

(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and social context
(i) a recognition of the need for, and ability to engage in life-long learning
(j) a knowledge of contemporary issues

Many other employer and professional groups have provided descriptions of the professional skills that are needed for engineers today. Many of these groups have independently concluded that professional skills are of greater importance today than ever before, and that the educational process for engineers does not adequately address them.

For example, more than two decades ago, **IBM** began a call for the creation of the "T-shaped" engineer. Beginning with a study in 1990 of hybrid managers[23] then progressing to a call for T-shaped skills and finally to T-shaped professionals, IBM became convinced that a new hybrid field of "service science, management and engineering[24]" is needed in the 21st century. This field depends on a workforce comprised of T-shaped individuals. The IBM concept of the T-shaped individual is illustrated in Figure 1.

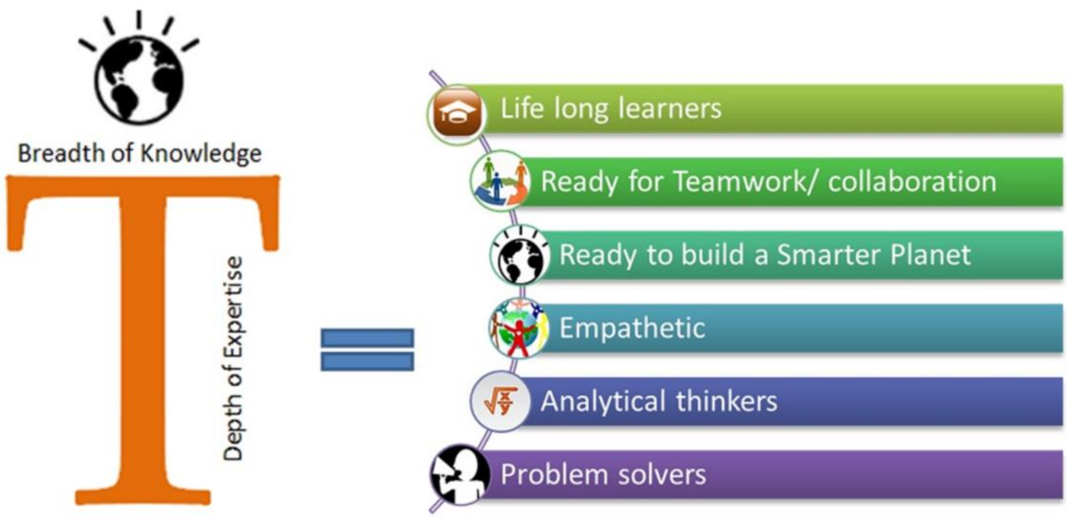

Figure 1 – **The IBM Concept of the T-Shaped Individual**[25]. The vertical bar represents depth in a single technical discipline, and the horizontal bar represents the ability to apply knowledge across disciplines and to work with others.

The inclusion of human services within the engineering disciplines is gaining recognition within the engineering profession. In 2015, IBM chairman, president, and CEO Virginia Rometty was elected to the National Academy of Engineering for her leadership at IBM in establishing the field of services science.

Recently, the **Council on Competitiveness** with support from Lockheed Martin Company and others sponsored the National Engineering Forum[26]. According to their website, *"The National Engineering Forum (NEF) is a movement focused on creating solutions for challenges facing the U.S. engineering enterprise – capacity, capability, and competitiveness – the 3C's. Momentum-building regional dialogues involve leaders from industry, academia, the media, non-profit organizations, and government in shaping*

[23] Palmer, Colin, *"Hybrids—a critical force in the application of information technology in the 1990s,"* **Journal of Information Technology**, Vol. 5, (1990), pp. 232-235.
[24] http://researcher.watson.ibm.com/researcher/view_group.php?id=1230
[25] "*Why Do You Need to Become a T-Shaped Person*," **Students for a Smarter Planet**, blogpost, July 3, 2013. http://asmarterplanet.com/studentsfor/blog/2013/07/why-do-you-need-to-become-t-shaped-person.html
[26] http://nationalengineeringforum.com/our-focus/#.VTRdVs74tlI

the agenda and building a community of action. The dialogues will culminate in a national cornerstone event in 2017." They explain that "capability" relates to the concerns about the need for **multi-disciplinary training** of engineers to meet the Grand Challenges, and "competitiveness" relates to concerns that **more creative and collaborative leadership** is required to build **partnerships with society through government and the media**. The NEF has sponsored about 20 regional meetings around the U.S. to discuss this agenda with a wide range of stakeholders and plans to convene a major national summit in 2017.

The **Business Higher Education Forum** (BHEF) is another broad-based group of industry and academic leaders dedicated to shaping the U.S. engineering workforce of the future. According to their website[27]: "*The Business-Higher Education Forum is the nation's oldest organization of senior business and higher education executives dedicated to advancing solutions to U.S. education and workforce challenges. Through the member-led National Higher Education and Workforce Initiative, BHEF is committed to developing new undergraduate pathways needed to keep regions, states, and the nation economically competitive. BHEF and its members drive change locally, influence public policy at the national and state levels, and inspire other leaders to act. BHEF works with its members to develop undergraduate programs in emerging fields that can be applied to a variety of professions to correct workforce misalignment."* The BHEF is active in developing definitions of "**workplace competencies**" and "academic content knowledge" that align better with emerging national needs and launching partnerships between industry and academia aimed at creating innovative new programs to shape the future workforce in engineering.

The **STEMconnector** is another organization involving a broad community of more than 3,700 national, state, local, and federal STEM organizations. As described on their website: *"STEMconnector® is a consortium of companies, nonprofit associations and professional societies, STEM-related research & policy organizations, government entities, universities and academic institutions concerned with STEM education and the future of human capital in the United States…"* Of particular interest is a recent STEM Innovation Task Force (SITF) that has been working for many months on the demand-side requirements of STEM professionals. Their report, STEM 2.0[28], provides an outline of their view of the professional skills needed for the STEM workforce of the future. The graphic in Figure 2 highlights their relevant findings.

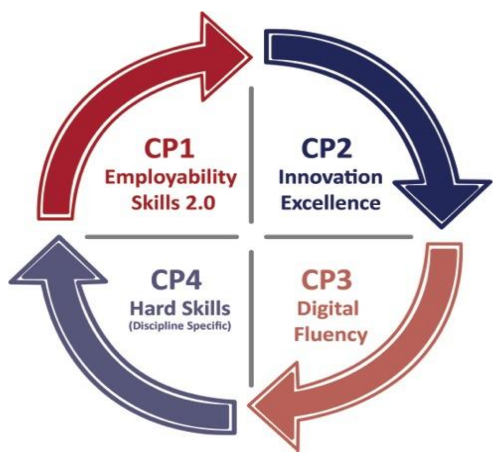

Figure 2 – STEMconnector Innovation Task Force report (STEM 2.0) on the competency platforms (CP) needed in the workplace today

As described in the report, "STEM 1.0 focused, rightly, on STEM content, whereas the next stage for our students and future workforce is to master **context**." The graph in Fig. 2 illustrates the four "competency

[27] www.bhef.com
[28] *STEM 2.0: An Imperative For Our Future Workforce*, STEMconnector Innovation Task Force, STEMconnector: Washington, DC, June 2014.

platforms" (CP) identified by the SITF as necessary to achieve STEM 2.0. In particular, CP1 and CP2 require a quantum improvement in professional skills.

Employability Skills 2.0 (CP1) are identified as "the **behaviors above and beyond technical skills** that enable STEM employees to create stakeholder momentum to commercialize ideas, or in short career skills. It is the ability to **present and 'sell' their ideas to others; to function in teams; to develop business acumen; to develop leadership skills; to navigate across a complex matrix of global organizations**."

Innovation Excellence (CP2) requires developing the "process of transforming ideas into new and improved systems, services or products that enhance the value of existing resources or create new ones. Innovators **identify opportunities** and use them to **drive change**. Innovation excellence requires a **'hollistic' multi/trans disciplinary skill set**."

In addition to these recent industry studies and reports, the **National Academy of Engineering** has also endorsed similar increased emphasis on professional skills. For example, the **NAE Grand Challenge Scholars Program**[29] was launched in 2009 to recognize and reward those engineering students who graduate with additional preparation in five areas beyond technical competence, including (1) a **hands-on project** or research experience related to a Grand Challenge; (2) an **interdisciplinary curriculum** that involves **public policy, business, law, ethics, human behavior, risk, and the arts, as well as medicine** and the sciences; (3) **entrepreneurship experience** that prepares students to develop market ventures that scale to global solutions in the public interest; (4) a **global dimension that instills awareness of global marketing, economic, ethical, cross-cultural, and/or environmental concerns**; and (5) **service learning that deepens students social consciousness and their motivation to bring their technical expertise to bear on societal problems**.

On March 24, 2015, more than 120 deans of engineering from across the nation presented letters of commitment to President Obama to establish a Grand Challenge Scholars Program on their campuses and graduate more than 20,000 engineers in the next decade with these enhanced professional skills[30].

These industry and academy reports are also supported by research results. For example, a recent thesis at MIT[31] involving a survey of nearly 700 mechanical engineering graduates about 10 years after commencement reported that students learned an extensive list of engineering science and mathematics subjects at MIT, but that they found much less use for this material in their career than they did for professional skills—which they mostly had to learn on their own after graduation. They reported that their current position required relatively little direct competence in the engineering sciences, but instead required substantial proficiency and even leadership in professional skills in order to advance. They reported that they used the professional skills daily but engineering and science much less frequently.

More recently, the NAE published a report titled **Educate to Innovate**[32] that, among other things, identifies the factors that influence innovation. As presented in the report, "the United States must significantly **enhance its innovation capacities** and abilities among both individuals and organizations. Innovation capacity should be a new indicator of US workforce readiness to compete successfully in the global economy…A **new educational paradigm is needed** to help current and future American workers remain competitive… Academic environments, from the earliest ages through continuing education, can be improved—and even designed—to enhance this ability…The skills and attributes identified in the study include: (1) **creativity**; (2) **dissatisfaction with the status quo**; (3) **intense curiosity**; (4) the **ability to identify serendipitous moments**; (5) **willingness to take risks and to fail**; (6) **passion**; (7) knowledge

[29] http://www.pratt.duke.edu/undergrad/students/grand-challenge-scholars-program
[30] http://www.nae.edu/Projects/MediaRoom/20095/130169/134046.aspx
[31] Wolfe, Kristin E., "*Understanding the Careers of the Alumni of the MIT Mechanical Engineering Department,*" S.B. thesis, Advisor: Warren E. Seering, **Massachusetts Institute of Technology**, Cambridge, MA, 2004.
[32] Bement, Arden, Jr., Dutta, Debasish, and Patil, Lalit, *Educate to Innovate: Factors That Influence Innovation*, National Academies Press, Washington, DC. 2015.

of their field; (8) the **ability to identify good problems/ideas**; (9) the ability to **work at the interface of disciplines**; and (10) the ability to **sell an idea**."

Although not directly aimed at engineering graduates, it is noteworthy that the **World Economic Forum** also recently published a report[33] that presents a new summary of the skills needed for the 21st century of all graduates. From the executive summary: "To thrive in a rapidly evolving, technology-mediated world, students must not only possess strong skills in areas such as **language arts**, mathematics and science, but they must also be adept at skills such as **critical thinking, problem-solving, persistence, collaboration, and curiosity**.

Now, collecting ideas from all of these sources, a partial list of the professional (or soft) skills that are needed might include the following:

A Summary of Professional Skills

- Ethical behavior and trustworthiness
- Employability skills, including self-confidence and positive outlook, accepting responsibility, perseverance, sincerity, respect for others, good judgment, etc.
- Effective communication, including advocacy and persuasion
- Effective collaboration including leadership, followership, and consensus building
- Resourcefulness and the capacity for independent learning
- Entrepreneurial mindset and associated business acumen
- Inter- and multi-disciplinary thinking
- Creativity, curiosity, and design
- Empathy, social responsibility
- Global awareness and perspective

(It's important to note that the skills identified here may not be completely independent. To my knowledge, there are no substantial research studies that undertake to identify the level of interdependence among these skills.)

DO THESE PROFESSIONAL SKILLS MAKE A SIGNIFICANT DIFFERENCE? The proliferation of independent industry reports calling for an improvement in professional skills while remaining nearly silent on the need to keep up with emerging developments in the hard sciences and technology demonstrates widespread agreement that more improvement is needed in soft skills than anywhere else. Except for a few special cases (such as cyber-security) it is difficult to find industrial reports that call for additional or new technical subjects in the engineering curriculum.

However, this raises the question of whether individuals that make the investment to develop these skills experience a difference in their personal career trajectory. One of the ways to approach this question is to review the advancement and financial opportunities available to those individuals in comparison to those with lesser professional skills. Naturally, competent engineers with well-developed professional skills stand out when leaders look for individuals to promote into leadership positions. In fact, in most cases, professional skills are far more important for senior leadership appointments than high levels of technical competence. Substantial financial reward usually follows advancement into leadership positions. Recent reviews of salaries of engineers[34] confirms that those who ascend into leadership (management) positions experience a significant increase in salary and benefits.

In addition, college placement officers also confirm[35] that for graduating seniors with similar technical preparation, those with well-developed professional skills consistently receive more employment offers and higher starting salaries than those without these skills. Interestingly, about 14% of the new

[33] *New Vision for Education: Unlocking the Potential of Technology*, **World Economic Forum**, Geneva, Switzerland, 2015.
[34] http://www.hamiltonproject.org/papers/major_decisions_what_graduates_earn_over_their_lifetimes/
[35] Sally Phelps, Director of Post-Graduate Planning, Olin College (personal communication)

employees selected at Google last year[36] had no college degree at all, in spite of the fact that Google receives tens of thousands of qualified applications. Lazlo Bock, Senior Vice President for People Operations at Google, explained that they sometimes look for qualities that do not line up with college transcripts. So, certain forms of professional skills are weighted more highly than a university degree at Google.

Finally, studies of companies that excel in the market place often reveal that the corporate culture plays a substantial role in their success[37]. Those companies with a culture marked by higher levels of professional skills tend to out-perform those that do not over the long term[38]. It is hard to identify a downside to building a company on a foundation of widespread professional skills.

> *"I want to talk with everyone about innovation. We often say that America and Europe are more innovative than us, that China's innovation is not good and that the education [jiaoyu] system is to blame. Actually, I think China's jiao is fine. The problem is with the yu. In terms of jiao, China's students test better than anyone in the world, but yu is about fostering culture and emotional IQ…* ***"[Innovations] will only come regularly if we rethink our culture, our yu, our having fun****… our entrepreneurs need to learn how to have fun, too..."*
>
> Jack Ma (founder of Alibaba)[39]

BUT CAN PROFESSIONAL SKILLS BE TAUGHT? Reviewing the list of professional skills, it is clear that these abilities extend beyond traditional course content knowledge and focus instead on a set of attitudes, behaviors, and motivations. Collectively, we might refer to these as a "mindset." But can education produce these attitudes or mindset? Is it possible to write a textbook, provide a set of lectures, and create a set of exams that will guide students to reliably develop the skills we seek? This is a difficult question that extends well beyond the boundaries of traditional engineering courses.

The fact is that attitudes and behaviors are only minimally affected by knowledge alone. They almost always require personal experiences that challenge beliefs and require extensive practice to build habits of mind. These psychological factors are largely unfamiliar to engineering faculty (and to many others, as well!). However, it is important to realize that business schools have long specialized in providing instruction aimed at improving teamwork and leadership skills, sales and marketing, entrepreneurship, etc. There are well established educational programs in these areas, although they may focus more on skills and knowledge than attitudes.

Consider the first professional skill in the list above: ethical behavior. Nearly every time a national scandal occurs in the financial world (like Enron, Bernie Madoff, or the recent Global Recession) business schools increase their emphasis on courses in business ethics. However, these courses are usually based on intellectual content derived from the philosophy of ethics with a focus on very complex decisions in cases involving trade-offs between two or more imperfect options. As fascinating and valuable as such courses may be to public policy debates, there is very little evidence that they are effective in reducing the likelihood that business graduates will avoid ethical violations themselves[40,41].

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36 Bock, Lazlo, "*Becoming a Googler…and Other Opportunities*," New York Times and Tom Friedman's ***Next New World Forum***, San Francisco, CA, June 12, 2014: http://www.nytfriedmanforum.com/videos/becoming-a-googlerand-other-opportunities.aspx

37 Collins, Jim, **Good to Great: Why Some Companies Make the Leap…and Others Don't**, Harper Business, 2001.

38 Collins, Jim, and Porras, Jerry I., **Built to Last: Successful Habits of Visionary Companies**, Harper Business, 1994.

39 Custer, C., *Jack Ma explains why China's education system fails to produce innovators*, **TechInAsia**, December 9, 2014.

40 Gentile, Mary C., Senior Research Scholar, Babson College, personal correspondence.

41 Gentile, Mary C., "*Values-Driven Leadership Development: Where We Have Been and Where We Could Go*," **Organization Management Journal**, Vol. 9, pp. 188-196 (2012).

However, a different approach that focuses on personal behaviors involved in confronting ethical violations in the workplace, together with practice in role-playing to build confidence and personal skills, has shown promise in changing mindset and behavior[42]. As in other examples of professional skills, the problem often lies not in a failure to understand at an intellectual level, but rather in a failure to develop the conviction and the skill to take personal action to address obvious problems when they occur—in spite of the personal inconvenience involved.

One of the most common goals of a liberal education is to produce “critical thinking” among graduates. Nearly all colleges and universities claim this as an important objective. But what, exactly, is critical thinking? One example might be provided by Dr. James Ashton[43] who, in the 1980s while serving in a leadership role at General Dynamics Corporation in producing the Trident Submarine, became concerned in comparing his personal observations with corporate reports on financing of the project. In an attempt to make sense of the situation, he drew the independent—and most inconvenient—conclusion that something was fundamentally wrong. This led him to confront top management with his independent analysis and ultimately to leave the company, eventually participating in a 60 Minutes interview with Geraldo Rivera and testifying before Congress. This sense-making, independent conclusion and personal action are all important ingredients in what we hope “critical thinking” really means.

However, it is interesting to compare this example with the most common method for producing critical thinking in higher education. In essence, critical thinking is assumed to result from the collective experience of taking a series of lecture courses for four years from highly educated faculty members who are experts in their research disciplines (but rarely in corporate practice). The courses are selected from several lists of approved electives, three from list A, two from list B, etc. However, some people have begun to question whether this whole approach is effective in producing the critical thinking we seek. After all, the students are exposed only to faculty members, not to practicing professionals. The environment they experience is that of academia that is marked with academic freedom, and not that of the competitive marketplace. There is rarely an independent assessment process intended to monitor the cumulative development of critical thinking.

For example, some years ago, President Liz Coleman of Bennington College in Vermont concluded that this process is fundamentally inept in producing critical thinkers (and other things), and she led a process of gut-wrenching change in her institution to literally reinvent a liberal arts college. She is now an outspoken advocate for such profound change throughout higher education[44].

Another of the professional skills on the list is that of an entrepreneurial mindset and associated business acumen. Over the last two decades, engineering schools have begun to accept that students should learn the basic principles of entrepreneurship. Twenty years ago, it was rare to find an engineering school that was willing to make room in the curriculum for this subject, whereas today it is difficult to find an engineering school that does not already have such a program or is in the process of creating one[45].

To meet the growing demand for teaching entrepreneurship in engineering, several well organized independent programs have been developed. One of the most successful is the Kern Entrepreneurial Engineering Network (KEEN)[46]. This network of 19 engineering schools around the U.S. is focused on graduating engineers with an entrepreneurial mindset, not just technical skills. The KEEN network has a well-developed educational approach involving four cornerstones: business acumen, customer engagement, technical fundamentals, and societal values. But developing an “entrepreneurial mindset” is their highest goal. (Other well organized educational programs focused on engineering entrepreneurship also exist, including the EPICENTER program at Stanford University[47].)

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[42] http://www.givingvoicetovaluesthebook.com
[43] http://www.olin.edu/about/presidents-council/james-e-ashton
[44] https://www.ted.com/talks/liz_coleman_s_call_to_reinvent_liberal_arts_education?language=en
[45] McMurtrie, Beth, *“Now Everyone’s an Entrepreneur,”* **Chronicle of Higher Education**, April 20, 2015.
[46] http://www.keennetwork.org
[47] http://epicenter.stanford.edu

There are many possible definitions of an entrepreneurial mindset. However, at the foundation it may rest on a powerful "can-do" spirit, a focus on opportunities rather than challenges, and the "abundance" mindset (which I will return to later). Of course, it takes much more than a mindset, but it may be hardest to define and cultivate the mindset.

I recently read an article in the Wall Street Journal that included an interview with President Peretz Lavie, President of The Technion in Israel[48]. The Technion is regarded as a significant factor in Israel's becoming known in many circles as the "start-up nation." The persistent existential threats faced by Israel would seem to fly in the face of this reputation as the engine of entrepreneurship for the entire region. However, in the article, President Lavie explains: " 'We have to be on our tiptoes and have to think ahead,' he said. To live here, he adds, one has to be optimistic—an essential attribute for entrepreneurs"[48]. Clearly, he believes that the unusually challenging environment in Israel may have strangely contributed to the development of an entrepreneurial mindset there.

Unpacking this for a moment, I believe what Professor Lavie is saying is that entrepreneurs are people who <u>must</u> be optimistic. They must naturally have a mindset that predisposes them to imagine a better future is always possible, and that future depends on our taking initiative and creating the change that will make it so. This is in contrast to an opposite (cynical) mindset that believes future improvement is hopeless, imagines we are victims of some larger system or circumstance, and focuses efforts on finding someone else to blame.

This explanation of an entrepreneurial mindset is clearly related to the contrast between a "scarcity" vs. "abundance" mindset. These concepts were explained by Stephen Covey:

> *"Most people are deeply scripted in what I call the Scarcity Mentality. They see life as having only so much, as though there were only one pie out there. And if someone were to get a big piece of the pie, it would mean less for everybody else.*
>
> *The Scarcity Mentality is the zero-sum paradigm of life. People with a Scarcity Mentality have a very difficult time sharing recognition and credit, power or profit – even with those who help in the production. The also have a very hard time being genuinely happy for the success of other people. …It's difficult for people with a scarcity mentality to be members of a complimentary team.*
>
> *The Abundance Mentality, on the other hand, flows out of a deep inner sense of personal worth and security. It is the paradigm that there is plenty out there and enough to spare for everybody. It results in sharing of prestige, of recognition, of profits, of decision making. It opens possibilities, options, alternatives, and creativity. …It recognizes the unlimited possibilities for positive interactive growth and development, creating new Third Alternatives. …It means success in effective interaction that brings mutually beneficial results to everyone involved."*[49]

It is much easier to teach "business acumen" and techniques like accounting or business plan development than it is to promote an entrepreneurial mindset. Obviously, this involves personal attitudes and behaviors, and derives from a special learning culture.

So, is it really possible in education to shape a student's mindset or mental outlook? I believe it is, at least to some extent. In fact, I believe it may be happening every time we interact with students—whether we are aware of it or not.

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[48] Wolfe, Alexandra, "*The Technion's Peretz Lavie on Technology and Education*," **Wall Street Journal**, Feb. 13, 2015.

[49] Covey, Stephen R., **<u>The 7 Habits of Highly Effective People: Powerful Lessons in Personal Change</u>**, Simon Schuster, 2004, pp. 219-230.

For example, last fall I heard in the popular press[50,51] about an experiment with young children related to the Thanksgiving holiday. Apparently, the teachers had noticed that their students had a very weak sense of the meaning of the holiday. The students did not associate Thanksgiving with a sense of gratitude. So, they applied a curriculum to develop a sense of gratefulness. This consisted of asking students in one classroom to keep a journal in which each day they wrote down a few things that happened for which they were grateful. At the end of the week, the teacher conducted a brief class discussion of journal entries, and after several weeks they conducted an open class discussion in which the students were asked to envision the future as they expect it to be. Not surprisingly, the students envisioned a future with many positive possibilities, and were looking forward to an opportunity to engage in making a positive difference in the world. However, in another classroom down the hall, they applied a curriculum that instead of requiring students to identify several things they were grateful for, they identified several things that they regarded as hassles. In other respects, the process was identical. It might not surprise you that at the end, they found that the hassles curriculum produced a student outlook on the future that was much less positive. Students in this case saw a future with negative events, frustration, and little to be grateful for. It did not result in a mindset of abundance. These results are consistent with published research in experiments with college students in the field of positive psychology[52].

> "*Reflect on your present blessings, of which every man has many, not on your past misfortunes, of which all men have some*"
> CHARLES DICKENS, (M. DICKENS, 1897, P. 45)

WHO SHOULD TAKE RESPONSIBILITY FOR TEACHING PROFESSIONAL SKILLS? Since engineering faculty members were hired for their expertise in the technical disciplines, rather than in professional skills, few of them are likely to be well-prepared to take responsibility for teaching the professional skills. Furthermore, in previous generations many people just assumed that the responsibility for preparing the attitudes and behaviors of students was that of the parents, not teachers. Other people have noted that students who have a co-op experience in industry (or similar substantial personal experience working in a professional environment) seem to develop professional skills at a noticeably higher rate than students who have no such experience. Furthermore, teaching professional skills appears to be much more complex and nuanced than teaching knowledge of even skills that may be easily defined and measured. As a result, there are many good excuses to not take responsibility for teaching these skills. Undoubtedly, this fact plays an important role in creating the unfortunate situation we find today where they are largely overlooked.

Perhaps engineering schools should begin by sending their students to a business school to take the programs already developed there. It is hard to ignore the well-developed educational programs in this area that are available in most business schools today. However, this avenue is rarely taken by engineering schools. Why is that? Is it because of the logistics or financial consequences involved? Is it because of cultural factors between the faculty in each school, or the cultural factors between students?

While it is perhaps the most costly alternative in terms of time and resources for an engineering school, I think a good case can be made that the best alternative may be for engineering schools to take responsibility for teaching these skills within their own programs. For example, when attempting to teach another of the professional skills—effective communication and writing—it is much more effective if these skills are embedded in every course in the school (i.e., "writing across the curriculum") than it is when sending the students to the English Department to take a course or two there. If we understand how

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[50] Marsh, Jason, and Keltner, Dacher, "*Thanksgiving and Gratitude: The Science of Happier Holidays*," **The Wall Street Journal**, November 28, 2014.
[51] Lyden, Jackie, "*Try and Be Grateful (You'll Thank Us Later),"* **On Point**, National Public Radio, December 24, 2014.
[52] Emmons, Robert A., and McCullough, Michael E., "Counting Blessings versus Burdens: An Experimental Investigation of Gratitude and Subjective Well-being in Daily Life," **Journal of Personality and Social Psychology**, 2003, Vol. 8, no. 2, pp. 377-389.

important professional skills are, and we want our students to respect them, then we should embrace them in everything we do. Adding at least a few faculty members within the engineering school who can take the lead in developing not just a curriculum, but a culture that builds professional skills, is perhaps the best approach. Then building a learning model that not only teaches about engineering, but teaches students to be engineers is how this can be integrated into the entire curriculum. This learning model should include a substantial engagement with industry, where the culture is authentic and is driven by market forces, rather than concerns about ideas alone and publishable research.

In summary, the time has come to embrace the professional skills and fold them into the mainstream in the engineering curriculum. No longer can we afford to pass the responsibility to someone else. We are the last stop on the educational train for our students—if they don't get these skills from us, where will they get them?

DISCUSSION QUESTIONS

1. How important do you feel professional skills are for engineers today? Which two or three skills do feel are most important for career success and for society?

2. Whose responsibility do you think it is to teach professional skills in engineering?