INVITED PAPER

Beyond 2020: Preparing Engineers for the Future

This paper examines the changes that are transforming the engineering profession and suggests the need for a sixth major shift: the integration of attributes of a global engineer, and concludes with the challenges and implications for future engineering education.

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ABSTRACT | Over the past 20 years, the world has seen significant advances in and adoption of new technology, political events that have led to the opening of formerly closed societies, economic policies that have encouraged free trade, and the growth in multinational companies. These changes have resulted in a world with increased connectedness and interdependencies and a globalization of the workforce. This paper discusses the impact globalization has had on engineering and engineering education.

KEYWORDS | Engineering education

I. BACKGROUND

Since the beginning of the 20th century engineering education has undergone several major shifts. An accompanying paper in this issue by Froyd *et al.* [1] identifies five major shifts during the past 100 years. Prior to the 1940s, engineering curricula at many universities focused on the practical aspects of engineering design including drawing, machining, and surveying. After World War II, the U.S. Government increased its investment in scientific research, which led to significant changes and advances in engineering and the way in which engineers were educated. Mathematics and the physical sciences played a more important role in engineering curricula, as did courses focused on engineering science rather than engineering practice. Froyd *et al.* [1] define this as the first major shift. By the 1980s, engineering graduates were well prepared technically, but industry was frustrated by the lack of professional development. Of particular concern were the weak communication and teamwork skills, and the lack of understanding of the importance of societal influences on engineering solutions [2].

In the early 1990s, engineering deans and industry leaders expressed concern about the readiness of engineering graduates to enter the workforce. Some deans felt the accreditation process used by the Accreditation Board for Engineering and Technology (ABET) imposed too many constraints on engineering curricula and stifled creativity for both the programs and the students. In response to these concerns, ABET's leadership established the Accreditation Process Review Committee to advise the organization on how to make the criteria more flexible without compromising educational quality. Input was gathered from stakeholders, including university presidents, deans, and faculty, industry leaders, private practitioners, professional and technical society liaisons, and executive directors. These discussions were the catalyst for Engineering Criteria 2000 (EC2000)—new criteria designed to accommodate differences and innovation in engineering programs. The new criteria changed the focus from curricular specifications to student learning outcomes and accountability. Additional information on accreditation can be found in [3] and [4]. Lattuca *et al.* [2] report in their study of the impact of EC2000 that students are better prepared than their counterparts of a decade earlier in all of the nine learning outcomes assessed. The most significant improvement occurred in student understanding of societal and global issues, the ability to apply engineering skills, teamwork, and their appreciation of ethics and professional issues. Froyd *et al.* [1] refer to these changes as the second major shift in engineering education with the three remaining shifts still ongoing: the emphasis on engineering design; the integration of education, learning, and social–behavioral sciences research; and the integration of information, computation, and communications

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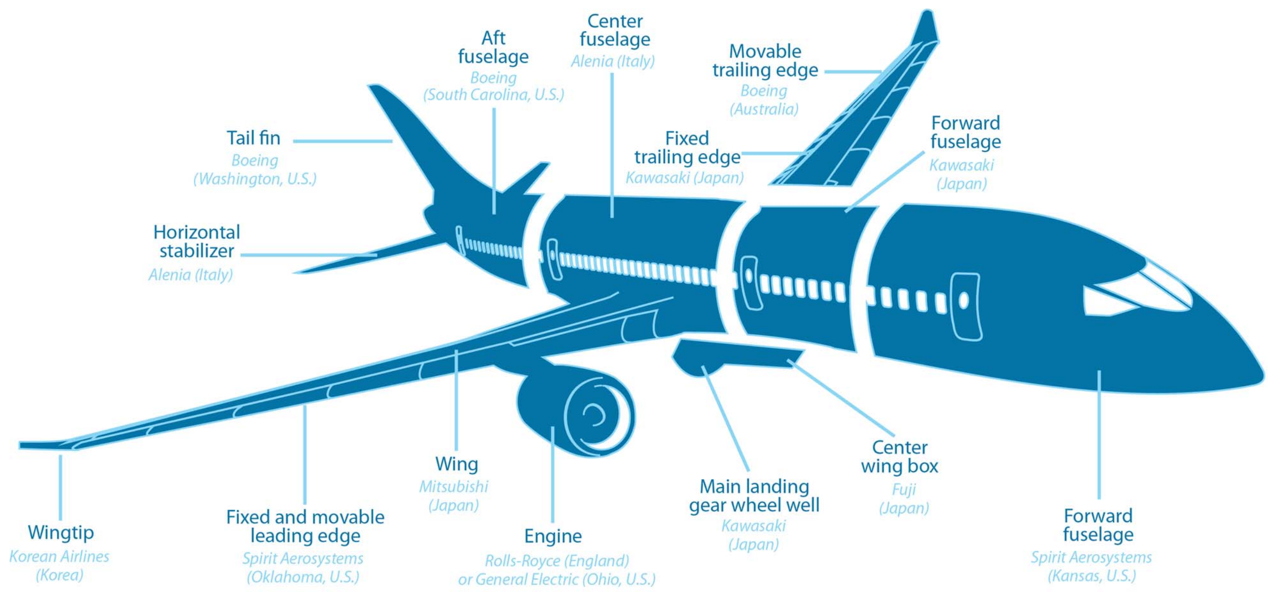

SELECTED SYSTEMS NOT SHOWN

Landing gear Messier-Dowty (France)	Wing-to-body fairing Boeing (Canada)	Landing gear doors Boeing (Canada)	Global collaboration tools Dassault Systèmes (France)	Passenger entry doors Latecoere (France)	Main cabin lighting Diehl Luftfahrt Elektronik (Germany)

Fig. 1. ***Why is educating a global engineer so important? Design and manufacturing of the Boeing 787 Dreamliner.***

technology. This paper identifies the need for a sixth major shift: the integration of attributes of a global engineer.

Since EC2000 was introduced in 1996, the world has seen many changes, including the development and global adoption of the World Wide Web, cell phones and wireless technologies, sequencing of the human genome, and creation of carbon nanotubes. We have experienced the inflation and deflation of the dot.com bubble and movement of manufacturing around the world. The world has become highly interconnected and interdependent, and the problems we face have become much more complex. Engineers are uniquely positioned to offer solutions, but are we prepared to do so?

A number of studies have documented the impact global forces have had and what the likely impact will be on the role of engineers [5]–[9]. In as early as 1997, Condit and Pipes articulate the need for change in engineering education in "A manifesto for global engineering education" [5]. The design of the Boeing 787 Dreamliner [10], [11] is an excellent example of the global nature of engineering today. Fig. 1 [10] illustrates who had responsibility for the major subassemblies and where they were manufactured. Table I [11] provides a detailed list of responsibilities and all the major contractors who worked with Boeing to design this aircraft. Significant advances in enabling technologies, political events leading to the opening of formerly closed societies, economic policies that encourage free trade, and the growth in multinational companies have all played a role [12]. As a result, we have seen an increase in the demand for engineering services on a global basis. This is motivating countries throughout the world to produce engineering graduates capable of meeting the needs and providing innovative solutions to the world's greatest challenges. The studies make clear that to be the most competitive, engineers must develop a broader set of competencies.

II. ATTRIBUTES OF A GLOBAL ENGINEER

Today, businesses are global and work is done around the clock and around the globe. The demand for well-educated engineers exists everywhere. It is also clear that to be the most competitive, engineers will need to embrace a broader vision of their professional role to respond to globalization and the global challenges [13]. While strong technical skills will continue to provide the foundation for all engineering disciplines, engineering graduates will need to demonstrate effective communication, creativity, entrepreneurial thinking, teamwork, and understand business in a global context.

A number of studies, workshops, and discussions provide us with a basis for defining a set of characteristics for a global engineer. For example, Parkinson [12] lays out a

TABLE 1 787 Dreamliner—International Team Facts

Company/Business Unit	Main Location	787 Work Statement
Boeing Commercial Airplanes	Washington, U.S.	Airplane development, integration, final assembly and program leadership
Boeing Charleston	South Carolina, U.S.	Aft fuselage
Boeing Fabrication	Australia, Canada, Washington, U.S.	Vertical tail assembly, movable trailing edges, wing-to-body fairing, interiors
Boeing Interiors Responsibility Ctr.	Washington, U.S.	Interiors
Boeing Propulsion Systems Div.	Washington, U.S.	Propulsion systems engineering and procurement services
Air Cruisers	New Jersey, U.S.	Escape slides
Alenia Aeronautica	Italy	Horizontal stabilizer, center fuselage
Astronautics Corp. of America	Wisconsin, U.S.	Electronic Flight Bag
Bridgestone	Japan	Tires
C&D Zodiak	Washington, U.S.	Sidewalls, window reveals, cargo linings, door linings and door surrounds
CTT Systems	Sweden	Zonal drying system
Dassault Systèmes	France	Global collaboration tools/software
Delmia Corporation	Michigan, U.S.	Software
Diehl Luftfahrt Elektronik	Germany	Main cabin lighting
Donaldson Company, Inc.	Minnesota, U.S.	Air purification system
Eaton Aerospace	United Kingdom	Pumps and valves
Fuji Heavy Industries	Japan	Center wing box, integration of the center wing box with the main landing gear wheel well
GE Aviation	United Kingdom	Common core system, landing gear actuation and control system, high lift actuation system
General Electric	Ohio, U.S.	Engines
GKN Aerospace	United Kingdom	Composite mat for the wing ice protection system
Goodrich	North Carolina, U.S.	Fuel quantity indicating system, nacelles, proximity sensing system, electric brakes, exterior lighting, cargo handling system
Hamilton Sundstrand	Connecticut, U.S.	Auxiliary power unit, environmental control system, remote power distribution units, electrical power generating and start system, primary power distribution, nitrogen generation, ram air turbine emergency power system, electric motor hydraulic pump subsystem
Honeywell	Arizona, U.S.	Navigation, maintenance/crew information systems, flight control electronics, exterior lighting
Intercim	Minnesota, U.S.	Software
Ipeco	United Kingdom	Flight-deck seats
Jamco	Japan	Lavatories, flight deck interiors, flight deck door and bulkhead assembly, galleys
Kawasaki Heavy Industries	Japan	Main landing gear wheel well, main wing fixed trailing edge, part of forward fuselage
Kidde Technologies	North Carolina, U.S.	Fire protection systems
Korean Airlines	Korea	Raked wing tips for the 787-8
Korry Electronics	Washington, U.S.	Flight-deck control panels
Labinal	France	Wiring
Latecoere	France	Passenger doors
Messier-Bugatti	France	Electric brakes
Messier-Dowty	France	Landing gear structure
Mitsubishi Heavy Industries	Japan	Wing box
Monogram Systems	California, U.S.	Water and waste system
Moog Inc.	New York, U.S.	Flight control actuators
Panasonic	Japan	Cabin services system, in-flight entertainment system
Parker-Hannifin	Ohio, U.S.	Hydraulic subsystem
PFW	Germany	Metallic tubing and ducting
PPG Aerospace	Alabama, U.S.	Electrochromic windows
Rockwell Collins	Iowa, U.S.	Displays, communications/ surveillance systems, pilot control system
Rolls-Royce	United Kingdom	Engines
Saab Aerostructures	Sweden	Large cargo doors, bulk cargo doors and access doors
Securaplane	Arizona, U.S.	Wireless emergency lighting system
Spirit Aerosystems, Inc.	Kansas, U.S. and Oklahoma, U.S.	Fixed and movable leading edges, flight deck, part of forward fuselage, engine pylons
Thales	France	Electrical power conversion, integrated standby flight display, in-flight entertainment system
Toray Industries	Washington, U.S.	Prepreg composites
Ultra Electronics Holdings	United Kingdom	Wing ice protection system
Vought Aircraft Industries	Texas, U.S.	Longerons, stringers, shear ties, and frame assemblies

Adapted from: Boeing 787 Dreamliner Technical Information, http://www.boeing.com/commercial/787family/dev_team.html rationale for the need for global competence and presents a set of global competencies and the results of a survey to engineering educators and corporate leaders who were asked to evaluate their relative importance. Engineers Without Borders (EWB) conducted focus groups of faculty students and industry to identify characteristics of a global engineer [14]. The American Society for Engineering Education (ASEE) Corporate Member Council (CMC) initiated the Global Engineer Project 2013 to develop and assess the skills and experiences required by engineering graduates to work effectively in a global environment [15]. The Global Engineering Deans Council (GEDC) held a workshop at the ASEE Global Colloquium for Engineering Education in Budapest, Hungary, in 2009, to define the characteristics of a global engineer [16]. Patil *et al.* [17] surveyed employers of engineering graduates from Monash University (Melbourne, Vic., Australia) to identify any competency gaps.

Parkinson [12] addressed three questions in an effort to define global competence. Why do engineering students need to have a new set of skills, which we will collectively refer to as "global competence?" What does it mean for students to have global competence? What are the most important attributes of global competence? In the following, we focus on the answers to the latter two questions.

Parkinson identified 13 characteristics that define global competence for engineering graduates. A graduate will be globally competent if he/she:

1) can appreciate other cultures;
2) is able to communicate across cultures;
3) is familiar with the history, government, and economic systems of several target countries;
4) speaks a second language at a conversational level;
5) speaks a second language at a professional/technical level;
6) is proficient working in or directing a team of ethnic and cultural diversity;
7) can effectively deal with ethical issues arising from cultural or national differences;
8) understands cultural differences relating to product design, manufacture, and use;
9) has an understanding of the connectedness of the world and the workings of the global economy;
10) understands implications of cultural differences on how engineering tasks might be approached;
11) has some exposure to international aspects of topics such as supply chain management, intellectual property, liability and risk, and business practices;
12) has had a chance to practice engineering in a global context, whether through an international internship, a service-learning opportunity, a virtual global engineering project, or some other form of experience;
13) views himself/herself as "citizens of the world," as well as of a particular company.

In an attempt to gain further insight, Parkinson surveyed university faculty and administrators and managers in industry. Respondents were asked to rank the attributes on a five-point scale, with five being the highest (essential). Twelve of the 13 attributes had a score of 3.0 (desirable) or higher. Attribute 3, focused on history, government, and economics, scored slightly lower than 3. The top five attributes for global competence were:

- 1: can appreciate other cultures;
- 6: is proficient working in or directing a team of ethnic and cultural diversity;
- 2: is able to communicate across cultures;
- 12: has had a chance to practice engineering in a global context;
- 7: can effectively deal with ethical issues arising from cultural or national differences.

Chan and Fishbein [14] compared the characteristics identified by EWB with the graduate attributes defined by the Canadian Engineering Accreditation Board (CEAB). The results of his comparison are shown below with the differences italicized:

1) understands the broad, *bigger picture context of engineering work*, including cross-disciplinary aspects, as well as the business and social implications;
2) has expertise in a specific field, but is comfortable in many engineering disciplines and able to work in an *interdisciplinary way*;
3) is a problem solver and is creative;
4) can adapt to new situations, *deal with complexity, and is skilled at systems thinking*;
5) is able to *collaborate on a global basis*, including *knowledge and/or understanding of people, culture, and language*, along with knowledge of collaboration techniques and software;
6) is able to communicate effectively both orally and in writing in English, and is *able to communicate across language and cultural differences*;
7) has an understanding of sustainability efforts and the ability to factor environmental impact and energy-use characteristics into *all aspects of his/her work*;
8) is *up to date on current world issues and emerging trends* and is constantly expanding his/her skills to be able to respond to these issues appropriately;
9) has a *well-developed sense of social responsibility and ethics, with due consideration in his/her personal and professional activities* for the world an society;
10) is *entrepreneurial* and is prepared to work with a varying level of resources and in various types of organizations in many different roles.

As Chan and Fishbein [14] note, "The engineer's role in society is no longer, if it ever was, limited to solving technical issues. Today, broader issues with society-wide and global implications require the profession's attention."

The ASEE CMC has developed, presented, and vetted a series of attributes with its stakeholders [15]. To validate the performance and proficiency levels of each attribute, an online survey was launched October 2010–September 2011 to solicit input from educators, employers, students, and professional engineers throughout the word. To gather input from around the world, the CMC partnered with the International Federation of Engineering Education Societies (IFEES) to translate the survey into a number of different languages. The survey was available in Chinese, English, French, German, Italian, Japanese, Korean, Polish, Portuguese, Russian, Spanish, and Turkish.

The attributes identified by the stakeholders represent the knowledge, skills, abilities, and characteristics needed by engineering professionals living and working in an increasingly global context. They include:

1) demonstrates an understanding of engineering, science, and mathematics fundamentals;
2) demonstrates an understanding of political, social, and economic perspectives;
3) demonstrates an understanding of information technology, digital competency, and information literacy;
4) demonstrates an understanding of stages/phases of product life cycle (design, prototyping, testing, production distribution channels, supplier management, etc.);
5) demonstrates an understanding of project planning, management, and the impacts of projects on various stakeholder groups (project team members, project sponsor, project client, end users, etc.);
6) demonstrates an understanding of the ethical and business norms and applies norms effectively in a given context (organization, industry, country, etc.);
7) communicates effectively in a variety of different ways, methods, and media (written, verbal/oral, graphic, listening, electronically, etc.);
8) communicates effectively to both technical and nontechnical audiences;
9) possesses an international/global perspective;
10) possesses fluency in at least two languages;
11) possesses the ability to think both critically and creatively;
12) possesses the ability to think both individually and cooperatively;
13) functions effectively on a team (understands team goals, contributes effectively to team work, supports team decisions, respects team members, etc.);
14) maintains a positive self-image and possesses positive self-confidence;
15) maintains a high-level of professional competence;
16) embraces a commitment to quality principles/standards and continuous improvement;
17) embraces an interdisciplinary/multidisciplinary perspective;
18) applies personal and professional judgment in effectively making decisions and managing risks;
19) mentors or helps others accomplish goals/tasks;
20) shows initiative and demonstrates a willingness to learn.

The survey resulted in 1027 usable respondents, with the data currently under analysis. Presentation and publication of the results are expected to occur in 2012 and 2013.

Although there are some variations in the identified attributes, there is also much consistency. In Fig. 2, we adapt Chang *et al.*'s [18] description of the 3-D global engineer. For future engineering graduates to be most competitive in a global context, they will be expected to demonstrate competency technically, professionally, and globally. To be *technically competent* graduates will need to demonstrate knowledge of: engineering science fundamentals and their technical discipline; design and manufacturing process; project management and innovation; complex, multidisciplinary systems; and a systems approach to engineering. *Professional competence* will require that graduates demonstrate: entrepreneurship; effective communication skills; leadership and the ability to work on diverse teams; flexibility, strong work ethic; curiosity and the desire to learn for life; and the ability to think critically and creatively. To be *globally competent* graduates will need to: understand global markets and business practices; communicate in a language(s) other than one's native language; work in multicultural global environments; understand global ethical, safety, and security standards; and have cultural, social, and political awareness.

To remain competitive our engineering graduates will need to develop broader perspectives and skills. The challenge for university faculty and students is think differently about engineering education and as Miller says [9], "we need to produce graduates with well developed multiple intelligences and a better balance between left-brain and right-brain abilities." This may take more than just changing the curriculum; it may take changing who is admitted into engineering programs, what faculty members are hired, and how we define an engineering education.

III. IMPACT ON ENGINEERING EDUCATION

One challenge for engineering educators will be defining the context for each of these attributes. Another will be determining what can be accomplished within the constraints of a university education. Parkinson [12] provides an interpretation for each of his 13 attributes. In what follows is a summary of his five top-ranked attributes. 1) *Can appreciate other cultures*: Does the graduate

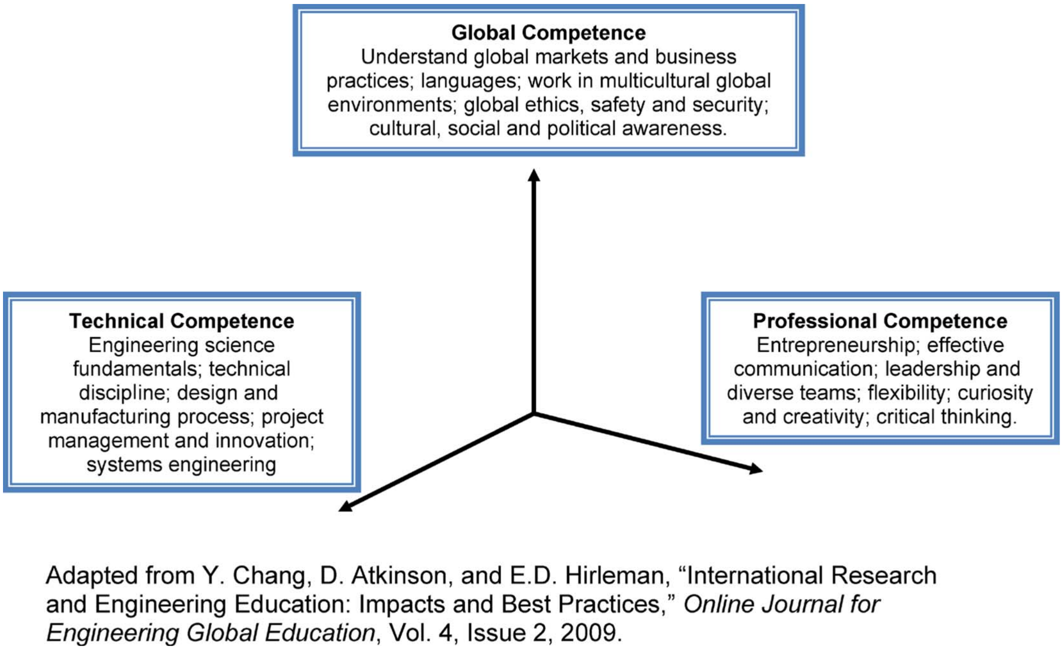

Fig. 2. ***Global Engineering Professional: The 3-D Engineering.***

understand and avoid ethnocentrism? As noted in [19], "All cultures, to some degree, display ethnocentrism, which can be the greatest single obstacle to understanding another culture." 6) *Is proficient working in or directing a team of ethnic and cultural diversity*: Since much of engineering work is done in teams and increasingly with team members across the globe, is the graduate able to communicate effectively across cultures? Is the graduate able to manage a team across time and geography? 2) *Is able to communicate across cultures*: Does the graduate understand the cultural differences in communication, such as the meaning of "yes," nonverbal cues, status, saving face? 12) *Has had a chance to practice engineering in a global context, whether through an international internship, a service-learning opportunity, a virtual global engineering project, or some other form of experience*. Has the graduate had the opportunity to experience working in or with someone from another culture? 7) *Can effectively deal with ethical issues arising from cultural or national differences*: Does the graduate know how to handle situations that may be considered unethical or illegal in his or her country, but are a common part of business in another country?

Once the attributes are defined, we can begin to think about how to integrate these concepts into the education we provide our students. But with engineering curricula already crowded, is there anything we can do? The answer is yes, but consistent with these attributes we will need to be creative and flexible and take advantage of a student's entire university education. We also need to recognize what the potential barriers are so strategies can be put into place to overcome them. In November 2008, a summit meeting on the Globalization of Engineering Education was organized by Grandin and Hirleman [20]. Among other important topics, the group discussed possible obstacles to integrating international experiences in a student's education. Specifically, participant Janet Elzey shared a list of 16 obstacles she had identified. These include but are not limited to a lack of tradition, curricular rigidity, lack of support (colleges, departments, faculty, study-abroad professionals), financial restrictions (university, student), lack of reward structure for faculty, and monolingualism.

Given all the challenges, how do we find a path forward? In an ideal world, e.g., Olin College (Needham, MA), we can create a totally new and different educational experience. Unfortunately, most of us are not in a situation where this is possible. We must build on what already exists. Grandin and Hirleman [20] document a number of strategies universities have been using to better prepare students for global competence. These strategies include double major or dual degree programs, minor or certificates, international co-ops or internships, international projects, study abroad or academic exchanges, collaborative research and design projects, service learning projects abroad, and graduate-level international programs. Unfortunately, even with this range of possible opportunities, according to the Institute of International Education only 4% of U.S. engineering students studied abroad in 2009–2010. To really have an impact, the importance of global competence will have to be valued and given priority.

An example of a very successful student exchange program is the European Commission's Erasmus Programme. In 2009–2010, there were 213 266 Erasmus student mobilities that included 177 705 students studying abroad and 35 561 students doing internships. In addition, Erasmus supported 37 776 Erasmus faculty mobilities including 29 031 teaching assignments and 8745 faculty training periods. A total of 2982 higher education institutions participated in the program. The success of this program is due to the strong commitment of the European Union's educational institutions and the priority given on the EU's political agenda [21].

Individual universities can also make a difference. In 2008, the College of Engineering at Purdue University (West Lafayette, IN) launched a five-year strategic plan entitled Global Engineering Program: Leadership through Global Impact [22]. The goals include facilitating participation of Purdue's engineering students in international study and service learning programs, enhancing students' ability to develop critical social and professional skills, integrating global competencies in the engineering curricula, and developing methodologies for assessing impact. Various strategies have been implemented to achieve these goals, including the creation of a Global Design Team to provide support for faculty and students, establishment of the Purdue College of Engineering as a Global Hub (a depository for discovery, learning, and engagement opportunities), facilitation of opportunities for faculty to share their expertise in the larger global community, and providing seed grant opportunities to encourage global engagement. As a result of these efforts, students are engaged in a larger number of study/work abroad and global service learning opportunities, faculty are participating in more global research collaborations, and there has been increased global awareness on campus.

IV. SUMMARY

Today, as never before, the world is connected and interdependent resulting in a demand for well-educated engineers throughout the world. To succeed in this environment, engineers will need to embrace a broader vision of their professional role. While strong technical skills will continue to provide the foundation, engineering graduates will need to demonstrate effective communication, creativity, entrepreneurial thinking, teamwork, and understand business—all in a global context. We truly will need to have a 3-D perspective that encompasses technical, professional, and global attributes.

As engineering educators, we will need to think differently about the education we provide our students. We will need to find ways to integrate student learning and student life, so upon graduation our students will have developed their technical, professional, and global attributes they need to be successful.

As Vest [13] so eloquently states, "As we think about the challenges ahead, it is important to remember that students are driven by passion, curiosity, engagement and dreams. Although we cannot know exactly what should be taught, we can focus on the environment in which they learn and the forces, ideas, inspirations and empowering situations to which they are exposed." ■

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