The Three Axes of Engineering Education

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***Abstract* – The goal of this paper is to encourage educators to recognize that engineering education is now comprised of three key axes: technical, professional and global skills. Just as research has shown that the incorporation of professional skills can strengthen students' technical skills, the expectation is that global skills can similarly enhance overall engineering curriculum outcomes. This paper makes two recommendations: (1) That proven methods used to incorporate professional skills into the curriculum be adapted to provide a baseline global education for all engineering students; and (2) That team-based study abroad programs be employed to provide internationally minded students with advanced global competency skills.**

Key Words - ABET, Global Engineering, Professional Skills, Global Teams, Global Competency.

INTRODUCTION

Industry, government and academic leaders have strongly emphasized the need for U.S. schools of engineering to matriculate globally competent engineers. Incorporating global competency skills into an already compacted curriculum is a significant challenge. Past experience, however, demonstrates that U.S. schools of engineering can successfully adapt to such challenges. Throughout the late 19th and early 20th centuries, engineering educators focused largely upon applied technical courses and research was considered to be the scientists' domain. Although the need for research was recognized as early as World War I, the majority of U.S. institutions only embraced engineering research after the launch of Sputnik in 1957. Another major educational shift occurred in the late 1980s, when industry began conveying a strong need for engineers with professional skills such as teamwork, communication and leadership abilities. Despite concerns, research has shown that incorporating professional skills into the curriculum has increased students' technical proficiency[1]. The goal of this paper is to encourage engineering educators to engage in defining and developing global competency as a third axis of engineering education (Fig. 1). By looking to proven methods, ranging from case-based instruction to team-based study abroad engineering programs, global competency can be embedded into engineering curriculums. Significant advances, however, can only be made if engineering educators proactively research and standardize this third axis.

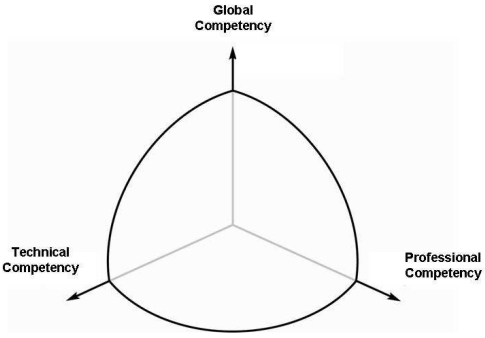

FIG. 1: THE THREE DIMENSIONS OF GLOBAL ENGINEERING EDUCATION

THE TECHNICAL AXIS

Throughout the 19th century, an engineer's training was largely limited to apprenticeships[2]. By the 20th century, schools of engineering were developed but their curriculums mimicked the nature of apprenticeship, with classes focused upon practical training rather than theory and mathematical analysis[2]. The need for strengthening the field of engineering education became starkly evident during World War II when the U.S. relied far more upon scientists than engineers to develop key technology such as radar and nuclear fission[3]. In 1955, the American Society of Engineering Education established the first criteria for modernizing engineering education[4]. This criteria, know as the Grinter Report, emphasized the need to modernize engineering education by: 1) upgrading the scientific and mathematical foundation; 2) strengthening the design requirement that distinguishes engineering from most college programs; and 3) recognizing the obligations of the profession to society[3]. "At first, these criteria were resisted, but the launching of Sputnik in 1957, and their

ensuing adoption as … accreditation requirements, accelerated their acceptance," stated Dan H. Pletta of University of Virginia, who served as secretary for the committee during its three-year tenure. "New courses were introduced and obsolete ones were eliminated"[3].

The Grinter Report's recommendations provide a useful lens into the typical curriculum of that era. The Report recommended that ten percent of an engineering curriculum be dedicated to electives, about one-fifth to humanistic and social studies, and about three-fourths to technical courses.[4] Professional skills such as communication and business acumen were limited to these electives and humanities. This technology-centric curriculum remained steadfast throughout U.S. schools of engineering well into the 1980s.

THE PROFESSIONAL AXIS

In 1985, the National Research Council issued a study that spotlighted the need for universities to graduate engineers with professional skills.[5, 6]. This message was reinforced through a 1994 joint report published by the Engineering Deans Council and ASEE[7] that stated, "Today, engineering colleges … must educate their students to work as part of teams, communicate well, and understand the economic, social, environmental and international context of their professional activities."[7] Although these reports raised the profile of the need for engineers with professional skills, two key factors are frequently credited for sparking actual curriculum changes: federal funding and new accreditation requirements [2, 3, 8].

In 1993, the National Science Foundation created Engineering Education Coalitions that developed the first education-focused funding opportunities, such as the Course, Curriculum, and Laboratory Improvement (CCLI) grant program[8]. And in 1996, the Accreditation Board for Engineering and Technology (ABET) Board of Directors adopted a new set of standards, called Engineering Criteria 2000 (EC2000). The EC2000 standards required all schools of engineering to fold professional skills – such as solving unstructured problems, communicating effectively, and working in teams - into their courses by 2001. These two proactive forces for change empowered U.S. schools of engineering to more aggressively expand their courses into broader, two-dimensional curriculums.

The effectiveness of this two-axis curriculum was examined through a 2006 study conducted by Lattuca, Terenzini and Volkwein of Penn State[1]. The researchers surveyed 39 deans and more than 1,200 faculty regarding the impact of EC2000. Half to two-thirds of the faculty members surveyed said they incorporated professional skills by increasing their use of active learning methods (such as group work, design projects, case studies, and application exercises) into a course they teach regularly. The study concluded that although three-quarters of those interviewed said their school of engineering did implement a moderate-to-significant increase in professional skills into the curriculum, few felt this caused them to reduce their emphasis on foundational topics in math, basic science, and engineering science[1]. Faculty members reported they have made significant changes to their instructional methods including[1]:

- Computer simulations: 2% decrease; 67% increase
- Application exercises: 2% decrease; 65% increase
- Case Studies: 2% decrease; 60% increase
- Open-ended problems: 4% decrease; 54% increase
- Design Projects: 6% decrease; 54% increase
- Use of Class Groups: 5% decrease; 52% increase

In addition, the study determined that students' technical skills were even stronger after EC2000 than before. The researchers reviewed nine testing criteria of engineering graduates (such as the GRE, ACT and CBASE) and determined that the students' mean scores in three technical areas – Applying Math & Science, Experimental Skills and Applying Engineering Skills – were all higher in 2004 than in 1994 (see Table I)[1]. This finding is key because it shows that not only is it possible to teach professional skills without sacrificing an engineering student's technical proficiency, but these proven techniques can serve as a roadmap for teaching global competency skills as well.

TABLE I: PRE- AND POST-EC2000 RESULTS[1]

	1994 Graduates	2004 Graduates
Applying Math & Science (Criterion 3.a)	4.02	4.07
Experimental Skills (Criterion 3.b)	3.73	3.91
Applying Engineering Skills (Criterion 3.k)	3.56	3.95

THE GLOBAL AXIS

Teaching global competency has become an imperative for schools of engineering. Corporations are competing in an international, knowledge-driven economy and many are adapting by creating engineering consortia that blend team members from several nations. The relationship between these multinational team members is critical because a corporation's investment into an overseas technical assignee can exceed $1 million.[9] Despite these major investments, 44% of multinational companies report failed expatriate assignment in the Asia-Pacific region and 63% of companies report expatriate failures in Europe.[9] The National Academy examined this issue in a recent report entitled *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*, concluding, "U.S. engineers must become global engineers .... The

engineer of 2020 and beyond will need skills to be globally competitive over the length of her or his career." [10]

The National Association of State Universities and Land Grant Colleges' Committee for International Education (NASULGC), which was composed of a variety of academic leaders from all fields, prepared a summary of the characteristics that define a globally competent student. In sum, the committee concluded a globally competent student has the following five characteristics: (i) Has a diverse and knowledgeable worldview; (ii) Comprehends international dimensions of his/her major field of study; (iii) Communicates effectively in another language and/or cross-culturally; (iv) Exhibits cross-cultural sensitivity and adaptability; and (v) Carries global competencies throughout life. [11]

Lucena, Downey and Moskel have proposed a learning criterion specifically for the global competency of *engineering* students. "Through course instruction and interactions, students will acquire the knowledge, ability, and predisposition to work effectively with people who define problems differently than they do." [12] As hosts for the 10th Annual Conference for International Engineering Education in November 2007, Purdue is organizing a workshop in which leaders of the field of global engineering competency can convene and develop a *consensus* definition for global engineering competency. This will provide a much-needed, standardized definition that will serve as a foundation for future research efforts specific to the field of global engineering competence.

Integrating the Three Axes:

The nature of engineering education is constantly evolving. The three axes acknowledge the recent accommodation of teamwork skills, entrepreneurial know-how and product development into the continuing technical core of engineering studies. We propose that the global skills axis provides context for the professional and technical work required of engineers on a daily basis.

Incorporating global competencies into the engineering curriculum will require additional investment by universities. The United States repeatedly falls short on indicators of international knowledge, awareness, and competence[11]. Despite such shortfalls, schools of engineering are increasingly expected to prepare globally competent engineers. The demand can be met by actively moving from a two-dimensional to a three-dimensional curriculum axis. In the 1950s and again in the 1980s, schools of engineering have shown their capacity to adapt to industry's needs without sacrificing their foundational commitment to their technical curriculum. We contend that the same advances can be made by recognizing global skills as the third new axis of engineering education and embedding global competency into each engineer's matriculation requirements.

We submit that four methods can effectively integrate the three axes into the daily engineering curriculum. These methods are: (1) adding a topical course into the curriculum; (2) strengthening the language requirements within the curriculum; (3) incorporating international case studies into existing technical courses; and (4) infusing study abroad opportunities with engineering-based teamwork. Each of these options is examined below.

Topical Courses – A clear option for addressing a new need in education is to develop a course tailored to teaching cultural awareness to engineers. The most prominent example in this case may be "Engineering Cultures," which is a liberal arts course developed by Downey and Lucena and taught at the University of Virginia and the Colorado School of Mines, respectively[12]. This course uses historical and ethnographic material to explore engineering cultures around the world including Britain, France, Germany, Japan, Mexico, Soviet Union/Russia, and the United States, focusing on what counts as engineering and engineering knowledge from country to country. Downey et al. (2006) state that the relative success of this elective course demonstrates that it is possible to provide undergraduates with some of the knowledge, skills, and predisposition required to work with engineers from different countries without a study abroad experience[12],.

Downey et al state, however, that Engineering Cultures is "an example of an integrated classroom experience designed to enable larger numbers of engineering students take the critical first step toward global competency[12]." The NASULGC Task Force on International Education echoes this opinion, stating, "These skills are not gained by completing a single global studies course—no matter how well designed or taught[11]." The task force's recommendation for teaching global competency were for universities to infuse international perspectives across all courses and majors, engage students from foreign countries in co-creating multicultural environment and promote student participation in foreign language courses and study abroad programs; that is, universities should offer "experiential" as well as "academic" opportunities .

Language Coursework - Placing a stronger emphasis upon the study of foreign languages is considered a very effective method for raising cultural awareness[11]. However, only one in 10 American college students studies a foreign language[11]. This decline mirrors the percentage of four-year institutions that have language-degree requirements. According to a 2002 American Council on Education (ACE) survey of more than 750 colleges and universities nationwide, only 23% had a foreign-language entrance requirement, and 37% had a language requirement for **all** students in order to graduate[13]. In fact, between 1965 and 1995, the

percentage of four-year institutions with language degree requirements declined from 89% to 68%[13].

Among all majors, engineers are the least likely to have language courses included as a graduation requirement. A 1988 survey of 122 four-year universities determined that only 4.1% required engineering majors to study a foreign language. This was by far the lowest of the nine general majors surveyed, with Business majors as the next lowest at 7.4% and Humanities as the highest at 77.7%[14]. A promising element, however, are the number of engineering students who studied a second language in high school or speak another at home. A 2005 study of Penn State engineers determined that 33% of the 186 native-English speaking engineering students surveyed had studied a foreign language for five years or more (29% of males and 47% of females). When this number of students is combined with the students who speak another language at home, the study found 49% of the students have a foreign language ability of "good" to fluent[15]. The study concludes, "Minors (~6 university courses) and certificates (~4 university courses) in both global engineering and foreign languages should be encouraged more, since that is where the market potential is[15]."

Case Studies – Due to the difficulties administrators face with incorporating an additional topical course into the curriculum, a viable first step is weaving international case studies into existing technical courses. Case studies are largely the same method used by schools of engineering to address industry's need for graduates with professional skills. Based on that success, it can be considered well-founded to state that these global case studies will prove to be an affordable and effective method for teaching the increasingly important skill of global competency. Nauman and Yadav of Purdue are currently developing several case studies, all with the specific theme of international approaches to engineering problems, into a variety of 2nd- and 3rd-year undergraduate Mechanical Engineering courses. Each case study will highlight the various approaches engineers from throughout the world use to solve the same engineering problem.

Engineering-Based International Programs – Although 75% of students think it is important to study or participate in an internship abroad during their academic career, less than 1% of all enrolled American undergraduates study abroad. Of these participants, engineers are among the least represented. Engineering and Computer Science students represent 14.1% of the total student body, but only 5.3% of study abroad participants. [16]. In contrast, Humanities represents 14.6% of the overall student body, but 30.2% of study abroad participants.

The following list of a few comprehensive programs reflects the diverse range of methods used by universities to move students along a pathway to global competence. (A more thorough list of global engineering education programs is available in Schuman[8]). The experiences offered by the following programs, coupled with Purdue's GEARE program discussed in detail below, can be viewed as a canonical set with different levels of experiences in three primary dimensions: language immersion; engineering professional immersion; and social/cultural immersion.

- The University of Rhode Island's International Engineering Program leads students simultaneously to degrees in both engineering (B.S.) and a foreign language (B.A. in German, French or Spanish.) Begun 19 years ago, IEP students study language and culture each semester along with their engineering curriculum. In the fourth year of the five-year program, students complete a six-month internship with an engineering-based firm in Europe, Latin America, or China.
- The Worcester Polytechnic Institute's Global Perspective Program was established more than 20 years ago. Over 50% of WPI students abroad to complete intensive two-month academic projects at eight international locations. The students work in small, multidisciplinary teams with local agencies and organizations to address open-ended problems that relate technology and science to social issues and human needs. About half of the projects, including most of those in developing nations, include a substantial service component.

THE PURDUE UNIVERSITY GEARE PROGRAM

The Purdue University College of Engineering has established a program that is a highly effective method for integrating the three engineering education axes into the curriculum [17, 18, 19]. The Purdue Global Engineering Alliance for Research and Education (GEARE) Program is a strategic partnership of leading global companies and universities. The College of Engineering at Purdue is committed to educating students as global engineers which, in our definition, includes being global citizens. Participants in the undergraduate GEARE program complete (i) language and orientation work; (ii) a domestic engineering professional experience with a global component; (iii) an international professional posting; (iv) a semester abroad taking engineering coursework; and (v) two semesters of global design team work (one at home, one abroad) on projects where the diversity of cross-cultural values impact the project decisions.

The GEARE program was created by the College of Engineering at Purdue University and its partners: Universität Karlsruhe (Germany); Shanghai Jiao Tong University (China); Indian Institute of Technology Bombay (India); and the Instituto Technologico De Estudios Superiores De Monterrey (Mexico). Students

from each university partner are treated in equally: the program is reciprocal in all of its substantial elements.

Prior to the creation of GEARE, about 1% of Purdue's mechanical engineering students had a global experience related to the engineering profession. In recent years 16 percent of Purdue's graduating students have had overseas courses or internships in their chosen field of mechanical engineering. In addition, GEARE has expanded to include students from other engineering schools at Purdue, including chemical, civil, electrical and computer, and aeronautics and astronautics.

There are two underlying premises of Purdue's GEARE Program. First, we hold that the most effective way for students to gain a substantive global perspective is for them to fully appreciate the variety of cultural values that are held around the globe. Secondly, we hold that the most effective way to achieve the necessary level of understanding is to create immersive learning environments where students must make engineering decisions that inherently require articulating, negotiating, and ultimately transcending differences among diverse cultural points-of-view as represented by their peers in global co-located teams. As such, we are also committed to designing learning environments and programs that support student success and to assessing the effectiveness of such instructional interventions.

We believe cultural values most clearly manifest when people make decisions. People become most acutely aware of the diversity of cultural values when making decisions as part of a team. Ideally that team has diverse membership and an appropriate problem to solve--one in which a successful outcome depends upon the effective collaboration of team members. The need for such complex solutions is the basis of the business case for diversity, i.e. the larger the array of perspectives brought to bear on a decision, the better the probability of making the best possible decision. The professional career of an engineer is a career of making decisions, almost always in collaboration with others. The important decisions often impact diverse consumers and distant citizens. In addition, the problems addressed are increasingly interdisciplinary. Due to the complexity of engineered systems today, it is rare for engineers to work alone. Engineers must collaborate and make decisions within a team environment. Whether determining what product to develop or specifying part of a manufacturing process, all of these decisions reflect to some degree the cultural values of the engineer or engineering team responsible.

A positive student experience with international team design involved the 2004-05 GEARE-Germany students, half of whom were from Purdue and half from Universität Karlsruhe. This group was integrated into two global design teams as part of a larger, multi-division design course on the Purdue Autonomous Vehicle Engineering (PAVE) project for the design and construction of an autonomous vehicle prototype. This design eventually led to the Purdue entry into a future DARPA Grand Challenge. During this 15-week project, a full-sized vehicle was developed from the initial project concept, through engineering design, procurement of parts and equipment, manufacturing and testing. An engine/transmission system of an existing automobile as well as some specialized sensing transducers was purchased from suppliers; all other components of the vehicle and its guidance and control systems were designed and built by the students.

The PAVE project, in particular, highlighted the communication challenges faced in a large-scale design. This student-coordinated project included over 125 students in four teams having specific design responsibilities in: guidance, drive train, chassis and suspension. Each team was made up of 4-5 groups with each group having specialized design responsibilities. The large scope and compressed time schedule of the project made effective communication between the various teams and groups a priority, impacting key design and manufacturing decisions. Cultural and education backgrounds heightened this communication challenge. Although the German students had excellent English skills, specific technical terminology was sometimes difficult. Also, the German GEARE students were initially reluctant to strongly advocate their ideas when challenged, but by the end of the semester many were assuming strong leadership positions within their groups. Overall, the development of communication skills was considered to be the best outcomes of the project by all involved.

THIRD AXIS: NEXT STEPS

Although experience has proven to us that GEARE is a highly effective method for integrating all three educational axes, formal assessment is needed. Assessment tools designed to quantify global engineering expertise and to provide valid cost-benefit measures are in the early stages of development. Consequently, it is unclear which aspects of any program are the most important for promoting technical, professional, and global excellence in engineering students. This deficit of information can make it very difficult for administrators interested in establishing global engineering programs to justify investing the resources required to foster global engineering expertise. A team of Purdue researchers with expertise in engineering education, assessment, and international programs are developing an assessment rubric to fill this void. The team will encompass quantitative measurements of learning styles, tolerance of ambiguity, intercultural awareness, expertise in designing systems for global markets, and the ability to demonstrate cultural awareness and incorporate best practices within a range of engineering cultures. The researchers will then apply this rubric to Purdue's GEARE program and compare the results of student participants to appropriate control groups. The results of this project will

allow universities, federal agencies, and industry to make informed curricular, funding, and hiring decisions in the area of global competency.

CONCLUSION

Engineer education is continually evolving. Industry and government leaders are looking to schools of engineering to provide new graduates with global competency skills. A key first step to facing this challenge is recognizing that engineering education is now comprised of three axes: technical, professional *and* global skills. Many critics fear that this expansion will weaken engineering students' technical skills, a fear that surfaced prior to both research and professional skills becoming staples of engineering education. A study of ABET's EC2000 program, however, has proven that just the opposite is true[1]. Technical skills have not declined; in fact, providing professional skills would appear to have been an enabling effect.

As a result, we are urging academic leaders to draw from their own past successes to incorporate global engineering skills into the curriculum. Methods such as case studies, topical courses, increased language requirements, and international team design and engineering-specific study abroad programs are all effective. The GEARE program is one effective educational method, but there are a wide range of global engineering programs available throughout the U.S. We are also urging engineering educators to continue formalizing the field of global education through research. Once university leaders are well-informed about the educational value, we anticipate that schools of engineering throughout the U.S. will, once again, adapt to the changing demands of our field by preparing students with *all* the skills needed for success.

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