INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN
ICED 05 MELBOURNE, AUGUST 15–18, 2005

TEACHING GLOBAL ENGINEERING DESIGN

Richard F. Devon, Sven G. Bilén, Javier Sánchez Sierra, and Peter Olfs

Keywords: Global engineering design, global economy, design education

1 Introduction

In this paper, we will draw upon a decade of experience of running global engineering programs in order to examine the nature of global design and how to teach it. We have run cross-national, bi-lingual design teams for eight years; industry tours in France for 5 years; established a global internship and cooperative education program; an international engineering certificate program; and helped establish a consortium for teaching global design of seven universities in four countries: Prestige. We have also twice taught a senior global design course, the second time with two industry executives—one of whom, Peter Olfs (a co-author), is a retired executive from a German multinational, Siemens, and the other, Audrey Russo, is from Alcoa, a US multinational.

Throughout this period we have been vexed by the question: what is global design? We have been looking at the way the practice of design is changing to embrace international and foreign standards, varied design cultures, distributed teams, the 24-hour clock, global markets, global supply chains, and cultural diversity with both its creative and its inhibitive effects. Because of the rapid and transformative nature of globalization, we believe that we have no choice about including an understanding of these processes in any global design course. Perhaps later, the global socio–technical systems will be better understood and more stable, and we can revert to a focus that is more solely technical.

The question of what is global design raises complex issues, but we think we can show that understanding them is important to engineering education and that design education—particularly innovative design education—may be far more important than is generally understood. We will present our case by first examining the significance of design in the global economy and then discussing the role of the global economy in design.

2 Design in the global economy

2.1 Globalization

There are many different conceptualizations of what is happening in the process of globalization and why. For example, in the forthcoming book, *Global Tectonics*, Ghadar and Peterson identify 12 major changes at work: population, urbanization, disease and globalization, resource management, environmental degradation, economic integration, knowledge dissemination, information technology, biotechnology, nanotechnology, conflict, and governance [1]. This list, in turn, is an expansion of the "Seven Revolutions" previously presented by the Global Strategy Institute of the Center for Strategic and International Studies (CSIS): population; resource management and environmental stewardship; technological innovation and diffusion; the development and dissemination of information of knowledge; economic integration, the nature and mode of conflict, and the challenges of governance [2].

Engineers might reasonably wish to do their work without becoming too informed about its social and economic context, but the changes are so large and so rapid, particularly in economic integration, that they may no longer have this luxury. There are many signs that the engineering education community in the United States is becoming alarmed about the growing strengths of the global economy, particularly in Asia. For example, a recent report by the National Academy of Engineering, *The Engineer of 2020*, stresses the impact of globalization on the practice of engineering and the necessity for U.S. engineers to focus on innovative and creative aspects of the profession to be globally competitive [3].

An alternate view of global competition, and particularly of the improvement in some Third World economies, is as a long overdue improvement in global equity among nations. Somewhat ironically, it is widely believed that all nations are losing sovereignty to the global economy and the multinationals that drive it, and increasing global equity among nations is paralleled by the decreasing significance of nation states, e.g., the European Union.

Often noted in discussions of engineering education and the global economy is the extraordinary growth of China's economy and of its higher education system. Half the graduates in China are engineers and scientists and China currently produces half of the world's engineers, or five times the number produced in the U.S. However, there are some moderating factors. This rapid growth has created at least temporary employment issues for engineering graduates in China, and their population is, after all, about five times that of the U.S. One can also note that U.S. engineers are paid approximately five times as much as engineers in China. Thus, the total market value of graduating engineers in the U.S. is similar to that of Chinese engineers—for the time being. However, the per capita rate for the production of engineers in Japan and South Korea is even higher than in either the U.S. or China and there is room to study the relationship between the production of engineers and economic growth [4]. Finally, it is worth noting that any alarm felt by engineering educators will not resonate with all industry leaders and policy makers in the U.S., since there is a very high level of economic cooperation between the U.S. and China (as well as Japan and South Korea), both for importing inexpensive manufactured goods that lower U.S. inflation and for return flows of dollars that finance the U.S.'s federal deficit. And U.S. corporations, like those of other countries, have been quick to see value in investing in China's manufacturing base.

2.2 Why teach our students global design?

In our global design course, our industry partners Peter Olfs (Siemens, retired) and Audrey Russo (Alcoa) taught our students how the global economy is shaping the context of design in terms of the production of engineers; the human and social capital needs of global corporations; the global flows of work to people and people to work; and foreign investments in the pursuit of comparative advantage. Olfs used case studies and role playing to show that the global economy is a *mélange* of players: national, regional, and international government agencies; multinational entities such as the World Bank and other multilateral banks; nongovernmental organizations (NGOs); and global corporations. After decades of experience in the global economy, he suggests that industrial practice takes place in a continuous web of shifting negotiations as resources, prices, and the economic power of the players change—and these changes are often dramatic, such as the rise of the Asian economies.

In his presentations, Olfs raised the often neglected issue of technology transfer. Early U.S. policy applications of this idea were efforts to help developing countries, such as President Truman's "Point Four" program in the 1950s and followed by President Kennedy's "Decade of Development" in the 1960s. Neither had much immediate success, except for the U.S. experts and U.S. companies who received most of the assistance. In the long term, the considerable early educational progress of some developing countries was probably very helpful to their later growth, e.g., the "Asian Tigers" and India. Technology transfer next emerged as a domestic policy issue in the 1980s as a U.S. initiative to commercialize ideas from government and university labs in order to be more competitive in the global economy (the Bayh–Dole Act). Now, technology transfer is significant again globally with the establishment of very successful industrial and R&D bases in many countries, even developing countries. For example, manufacturing practices are now remarkably similar in many, if not most, countries and labor costs and other incentives are driving the demographics of manufacturing locations. Olfs, in the global design course described below, noted that China insisted that a substantial portion of the first set of turbine generators for the Three Gorges Hydro Power Plant (won by consortia GE Canada–Siemens–Voith Hydro and GEC–Alsthom) had to be manufactured in China. Similar conditions applied to an order for locomotives (Siemens). In addition, each subsequent tender required a higher Chinese content. By learning to master the technology, China intends to become a competitor first in the Chinese market, then in Asia, and ultimately in the global market. Siemens' answer, observed Olfs, is to be faster than the Chinese with the next steps in innovation, thereby keeping a leading edge. Yet, with most of the direct foreign investment pouring into China, which adds to its huge trade surplus, how successful will this approach be—and for how long—as China builds its R&D infrastructure?

Another dimension to the complex issues surrounding the effects of the global economy is that of the "brain drain", i.e., the movement of people to work. The developed nations of North America and Europe have benefited enormously over the last four decades or so by the influx of foreign talent, many of whom came into their graduate schools, and particularly their graduate schools in engineering, science, and business. This talent resource is now in decline because of the growth of Third World economies and the growth of outsourcing: the movement of work to people. In higher education, which has played such a key role in the brain drain, this is causing a new concern: the loss of tuition revenues to global competition and restrictive post-9/11 visa policies in the U.S. (See the congressional testimony by Dan Mote, an engineer and president of University of Maryland [5].)

One final comment on the policy context of global design education is the issue of outsourcing. One analyst (Robert Reich) sees 80% of U.S. workers in the types of jobs that are getting outsourced and suffering income declines with a frequency that makes it politically very salient, while the most highly educated 20% are doing much better and enjoying rising incomes. To highlight this point, citing data from the Bureau of Labor Statistics, Forrester, Inc. predicts that the architecture and engineering industries, for example, will outsource 46,000 jobs in 2005, 70,000 jobs in 2008, and 191,000 jobs in 2015 [6]. However, if outsourcing is a factor for engineers, it would presumably show up in a softening of the market demand for engineers in the U.S. and there is no evidence for this even though the number of graduating engineers is increasing currently. In this case, too, outsourcing may increasingly affect engineering first in fields where the demand exceeds supply, such as in software engineering. U.S. corporations will continue to hire many U.S. engineers and increasingly we see foreign corporations actively recruiting U.S. engineering graduates, such as Siemens and GKN, in part because of their operations in the U.S. and, in part, for the perceived skill sets of U.S. engineering graduates.

Thus, we see a global economy affecting the U.S. with outsourcing increasingly penetrating professional and technical work, the international student resource decreasing, and the global percentage of engineering graduates in the U.S. falling to around 6% while their quality is still highly prized. Is there something that engineering education in the U.S. should do about this? After all, the numbers enrolling and graduating in engineering are up, and employment prospects are still good. And in addition to the recruitment by U.S. and foreign multinationals, there will always be a strong demand for engineers in the U.S. for domestic needs from local businesses and industries to public infrastructure works and defense. Despite this, the monolingual and mono-cultural nature of most U.S. engineering graduates when added to their lack of preparation for the global economy must be a cause for concern. So, as with issues such as global warming, it may be prudent to respond now rather than later when we know more but have fallen behind. We believe the issues are real and qualitative, rather than quantitative. We see some obvious strategies that engineering education in the U.S. can pursue, in addition to maintaining their current successes in quality at the undergraduate level and leadership in graduate programs and R&D.

2.3 How can higher education respond?

A study by the Design Council in the UK found that companies good at design outperformed the average company listed on the FTSE by 200% over a 10-year period, 1994–2003 [7]. A recent study in the U.S. by CHI Research found that the "top twenty-five S&P companies with patents that are most highly cited by papers and other patents" far outperformed the S&P 500 over 1990–2003 [8]. In addition, cross-national studies show a very high correlation between patents per million and a nation's standard of living [9].

If one accepts the significance of design as an economic driver, then one can infer that we must train our engineers to be prepared to succeed in the global economy, and one way to do this is by teaching global design. Another way is by teaching innovative design, although there is some overlap between the two. What is most serious about the situation for the otherwise high quality of engineering education in the U.S. is that both global design and innovative design are, at the moment, more absent than present in the curriculum, although there are positive signs of change. The main reason for their absence is the low status accorded design in the engineering curriculum.

U.S. schools of engineering (particularly large engineering schools) generally teach one design course in the first two years to help students feel good about engineering (i.e., as a retention measure) and one capstone design course in the last year—almost completely unrelated to the first design course—to prepare the students for professional work. Both are typically based on experiential learning with a single project absorbing much of the curricular time available. In total, this means only 5–7% of curricular time in a typical U.S. engineering degree is devoted to design and even specializing in design is not usually an option that is easy to pursue [10]. This situation is unfortunate since the practice of design has a direct and critical impact on the economy and at least 50% (a rising trend) of the engineering graduates of Penn State, for example, report design as a characteristic activity of their first job [11]. We appear, then, to be under-investing in design education in general, and in global and innovative design education in particular.

Thus, engineering education in the U.S. can respond best to the globalization of industry by teaching more design, and more global and innovative design in particular. As mentioned, these two areas overlap since inclusion of global diversity can play a very creative role in the design process.

3 The global economy in design

There are several ways in which the global economy affects design. We discuss here six needs that are addressed by participating in the global economy and how those needs shape design. In the Section 4, we then show how we have sought to expose students to these needs in global design courses.

3.1 Access to markets

The need to access markets in other countries is one of the primary drivers of the global economy. As markets become saturated locally, many companies seek to market their products in other countries. To do so effectively, they must understand that market, otherwise their products will fail. The following vignette provides an illustration of the importance of understanding the market in which a product is being introduced.

> "An American company has identified an overseas acquisition candidate with a great compatible product that could be brought across the Atlantic to expand its market reach in the U.S. Extremely popular in Europe, the product is of very high quality, promises great margins, and is nothing like anything available domestically. The price seems good and the company's financials appear in order.
>
> …
>
> "When U.S. sales of the product proved disappointing, a closer look at the market turned up some jarring revelations... Installation of the product, a vandal-proof floor-to-ceiling bathroom partition system, hampered sanitation procedures by making it more difficult to mop floors. In the U.S., the common maintenance practices of daily mopping and navigating in and out of many tiny rooms added significantly to maintenance costs.
>
> "The product's vandal-resistance features were important in Europe, less so in the U.S. In American schools, a major potential market for the partition, the vandalism problem is attacked by unionized janitors who are employed on an annual basis and are kept busy during summer months repairing and repainting damaged stalls." [12]

Illustrations such as the above, as well as similarly focused case studies, are particularly useful in showing students the motivation for understanding global markets. A design that is commercially successful in the U.S. may not make it in foreign markets, and vice versa.

3.2 Globally distributed design teams

The need to run globally distributed teams is necessitated by the need to understand foreign markets and to include the global diversity needed within the designs, while at the same time keeping costs within check. These teams may meet at some point(s) during the design process, but they also may not. Regardless, maintaining a high performing virtual, globally distributed design team using information technology is not an easy task. Yet, it is crucial as teams within companies are formed from entities located around the world. An illustration of the difficulty is provided by the following vignette.

> “In 1993, a group of nine architectural and engineering firms joined forces to see whether they could help each other expand into new markets without the risks associated with mergers, acquisitions, or opening new offices.
>
> “The plan was relatively simple. Firms would retain their autonomy, yet collectively bring the strength and reach of a mega-firm to clients through joint ventures and similar associations. What followed was the birth of STAR (Strategic Team of Allied Resources), a corporate alliance with a combined total of 47 offices and more than 2,000 employees.
>
> “Five years and scores of projects later, the alliance is still looking for that big, splashy commission that will raise its profile in the industry. But in the meantime, it has grown larger, more diverse, and more ambitious. Its ranks have swelled to 15 members, which include environmental and acoustical consultants. And in December, STAR hired its first CEO, who immediately changed its name to Global Design Alliance (GDA).
>
> “McCracken also indicated that GDA will continue placing most of its emphasis on domestic work. Thus far, the ability to combine the geographic diversity of large corporations with the personal service of a smaller, local firm has been GDA’s chief calling card in the U.S. (The alliance has 70 member firm offices in 22 states.) But that very strength also causes confusion among potential clients, who don’t always understand who—or where—the project coordinator is, or that GDA is a group of firms rather than a single entity. [13]

We run virtual global design teams now in several courses and find that it is not hard to reproduce the problems of distributed teams such as cross-cultural miscommunications, different time zones, scheduling issues, different educational formations, agendas and objectives, breakdowns in technology, and different public holidays. There is no choice, however, about getting on top of these issues and the students usually display very positive attitudes towards these collaborations. It has been made easier by advances in free software such as MSN Messenger and other messenger utilities, and VOIP such as Skype (as well as made harder with more firewalls appearing). After thinking for several years that the issue was going from point-to-point to multi-point, we have now taken running multiple teams concurrently as the more important next step. This allows for much longer team sessions and, unchecked, they usually run over an hour. Given the availability of free information technology, students can continue their relationships and their work between the scheduled conferencing times. They make friends easily and we put this first given the problem of trust and commitment in virtual relationships [14].

3.3 The 24-clock

The need to reduce time to market by using the 24-hour clock is also driving global design. Designs can be passed from one time zone to the next such that work continues unabated in order to achieve ever shorter times to market. Working within global design teams that are distributed across many time zones, and which usually change during the projects, is not easy and requires extensive coordination and scheduling. This is a frustrating aspect of virtual global design teams, but it mirrors reality and, insofar as it replaces air travel, it still provides for major gains in project management efficiency.

3.4 Global benchmarking

The need to benchmark globally and to understand the emergence of global practices is also an important driver in global design. Understanding how preferences and practices are changing globally, not just locally, is important for companies wishing to compete in the global economy. A vignette that describes this follows:

> "Fritz Mayhew, chief of North American design for Ford Motor, is among many designers applauding the direction their discipline is heading. 'Ten to 15 years ago there used to be marked differences between public design tastes in Europe, the United States, and the Asia Pacific markets,' he says. 'Europeans typically liked their products much more functional, straight-forward, kind of pure design, while we in America were still doing wood-grained toasters, for example. The same thing was happening in auto design. In the U.S. we were still using a lot of fake wood grain and living room-type front seats. All that has changed. Now design has become much more international.'" [15]

Within our global design courses, we require students to not only benchmark for products sold on the U.S. market, but also those sold in foreign markets. We also deliberately run customer/user needs assessment in each participating country.

3.5 Understanding varying standards

The need to understand industrial practices and standards that vary from country to country, despite ISO and increasing global conformity, is also critical. The "alphabet soup" of governmental regulatory agency stamps found on many products today attests to this fact. The designer may choose to design for the most difficult regulation, although these at times can be contradictory, as the following vignette illustrates:

> "Scientific Technologies Incorporated (STI) might be the U.S. leader in safety light curtains, but it isn't resting on its laurels. Company officials have their sights set on being a major player in the world market as well. And as the world's most compact safety light curtain, STI's MicroSafe^{TM} line is intended to help take them there.
>
> "The path to developing the MicroSafe, however, was an interesting one. Engineers had to contend with the vagaries of European standards, which were being written and modified even as the product was being developed. Meeting these standards wasn't a simple formality, either. Europe requires safety light curtains on certain types of manufacturing machines. UL is currently composing a standard for the United States, but it will probably be written around the European one, titled IEC 61496.
>
> …
>
> "The existence of the European IEC standard is a blessing wrapped in a curse. On the plus side, its existence makes for a mandated market for the devices. On the minus side, it spells out specific and critical performance requirements that STI officials say often favor technology from several European manufacturers, may restrict innovation, and placed constraints on MicroSafe's design. [16]

3.6 Cultural diversity

The need to harness the benefit of using cultural diversity in idea generation and knowledge development is the final need that we discuss. The distributed team research reports a U-shaped distribution between team diversity and team performance. Homogenous teams work well and well integrated heterogeneous teams can work even better, but there are well documented ways in which diverse teams fail [17]. However, team diversity represents an important resource in innovative design: a way to add value by adding new ideas. We have found results in students teams that confirm this [18].

4 Teaching global design

If teaching global design is important, we still need to discuss the how to teach those things that are important. We have outlined the "what" in Section 3 above and answer the "how" here. We teach global design by using global resources such as:

1. Globalizing the instruction, e.g., co-author and co-teacher, Peter Olfs
2. Cross-national design teams using information technology with five countries
3. Direct experiential programs
    - Global internships and coops in 8–10 countries
    - Focused academic programs such as
        - A 10-day industry tour
        - A 4-week, 3-country Nomadic Design Academy.

The content of teaching global design has settled on teaching about globalization, the demographics of the global flows of work and people, case studies of global engineering projects (usually large scale), the emergence of common practices such as in manufacturing, the adoption of ISO, global supply chains, and the use of distributed teams. Then, we study the role of diversity in national practices, in global markets, in cross-cultural communications, and in idea generation for new approaches to policies and in the design process.

Our strategy for teaching global design has evolved over the last eight years and now includes two courses: an honors section of the first-year Introduction to Engineering Design course and a senior-level Global Design Course. Study abroad and global internship programs are not discussed here.

4.1 Globalizing the instruction

A senior-level Global Design Course has been run twice at Penn State. The new Engineering Design Program (EDP) is focused on integrated design, the cross-cutting areas of design that apply to most fields of engineering [19]. In practice, it is focused on integrated design methods, design projects, innovative design, and global design. It is beginning a graduate program with such courses as innovative engineering design (e.g., TRIZ), design cognition, and the design of integrated systems.

The global design course had several resources of great value available to it. The corporate executives, Olfs from Siemens and Russo from Alcoa, were rated highly by the students. Olfs gave several 2-hour classes with presentations and discussions, including role playing examples and case study presentations to involve the students. His topics included case studies of global engineering projects, cross-cultural communications, and a review of the major players in the global economy. Russo focused on the rising significance of the human and social capital needs and costs of corporations, which are now sometimes the featured sections of annual corporate reports.

A second major resource came with the 11 students who were attracted to this optional global design course. Many already had experience of and in the global economy. The students began with a study of engineering design methods and gave presentations on global engineering topics. Two students presented their experience with the first Nomadic Design Academy (see Section 4.3 below) and showed convincingly the similarity of manufacturing methods in the three countries. Another student had worked for Bosch in Germany for two years and confirmed this finding while presenting his experiences as an American working overseas. A fourth student, a graduate in architectural engineering, described his experience building a hospital in Bosnia that was prefabricated in Germany. Prefabricated buildings obviously present a case where industrial engineering methods can apply in a different field of engineering. Finally, another graduate student presented his survey research on the increasing role of distributed teams and low cost engineering centers (LCECs) in global architectural engineering companies. The few “novice” students chose topics like the ISO and case studies of major engineering projects overseas.

4.2 Cross-national design teams

The Engineering Design Program at Penn State helped establish the Prestige Consortium, which consists of seven universities in four countries. It is dedicated to design education and preparing students for the global economy [20]. It features student travel for internships, distributed design teams, and a web resource site for design. We make heavy use of the consortium particularly when we run cross-national design teams.

Honors section of the Introductory Engineering Design course. This course includes a cross-national design project with students at a French university. The design problems come from both French and U.S. industries. The project lasts 8 weeks and the final documentation is in both languages. The teams collaborate entirely via information technology. (This project, Alliance by Design, was awarded an ACE/AT&T Award Technology as a Tool for Internationalization in 2003.)

This honors course also includes several other global design elements, such as a two-hour discussion and debate on the global economy featuring large scale global projects such as the Three Gorges Dam, the Millau Bridge, or the Tapei Towers, as well as a two-hour discussion and role playing experience on cross-cultural communications.

Collaborative design. Javier Sánchez Sierra of Tecnun (Universidad de Navarra, a partner in the Prestige consortium) collaborated on design projects for consumer products in the first offering of the global design course in the fall of 2003. This collaboration found a marked added-value effect of global diversity through more idea generation [10]. In the fall of 2004, he brought 16 of his third-year engineering students to another collaborative design project in which four teams of Tecnun and Penn State students tackled the same design problem. The problem, provided by the Penn State administration, was to redesign one of the few classrooms not recently remodeled.

The classroom redesign problem was also given to a class studying innovative engineering design methods. We thought we could compare innovation through learned methods with that inspired by global diversity. In the end the students did remarkably similar things, most notably switch the “portrait” orientation to a “landscape” orientation. The Penn State architect who handled the commission had originally downplayed this idea as impractical because of line-of-sight problems. The next semester, a team of students presented a design solution using the best ideas from both classes. The orientation solution was very well received and so were other changes that offer a great improvement for students and faculty with physical disabilities or who were too short to function effectively in the classroom.

The line-of-sight problem was solved by using two screens and a study of usage that suggested that the problem may occur only in 10% of the classes. For 90% of the classes they would be able to use the two screens for different displays, if they wished. The delivery area and first level of seating was kept at the same level as the corridor thus eliminating any need for ramps. The back two levels of seating were raised to allow visibility. Compared to the original, students would be closer to the instructor and the displays, and the floor being raised now allows much better visibility. This project is still active and it seems likely the student user-centered design will shape the remodeling effort in 2006–7.

4.3 Experiential programs

Honors section of the Introductory Engineering Design course. Ten U.S. students selected by performance in their design project in the Intro class then go the next summer on a one week tour of French industries followed by a cultural weekend. This is largely financed by the Schreyer's Honor's College at Penn State and there is no reverse program. This type of program is often disparaged for its brevity, but we routinely get high praise for it from our students. The impact as measured by qualitative assessments is very high and we have seen student social groups form during the experience that last until graduation and beyond. It is cost effective and, in particular, does not impact summer earnings since it takes place in mid-to-late May. Those who go on the 7–10 days tour also take a 1-credit cross-cultural orientation course before traveling.

Nomadic Design Academy. In the summer of 2004, Prestige began offering the Nomadic Design Academy (NDA) and sent students from Arizona State University Industrial Engineering Department (who organized the Academy), the University of Washington, and Penn State to four sites in Europe: University of Leeds (UK), IUT Bethune and École Centrale de Lyon (France), and Tecnun, the engineering school of the Universidad de Navarra in San Sebastian (Spain). The students spent a week at each site where they studied manufacturing and design topics and visited major engineering sites such as Rolls Royce in the UK and Mercedes in Spain. A website of results for the 2004 NDA was prepared by the students [21].

The NDA will run again in 2005 as a reverse program for EC students that will be hosted by the University of Washington Industrial Engineering Department for eight weeks of classes, industry projects, and site visits. The content of the NDA is currently rather more about manufacturing than design. This is much easier to do, but more design will be added as the program matures.

5 Conclusion

Global design is design where the global context is salient. Although the degree of salience varies, at some point the level is high enough to characterize it as global design. At this point in history we think a lot of things are brought into the design process that will not be there unless we call it global design. Teaching it means including an understanding of globalization, of who the players are in the global economy, of global practices in design, of distributed teamwork, and of the role of cross-cultural differences in creativity and communications. Just as we stress the value of project-based experience when teaching design, so we think the value of virtual and real experiences in global design are essential.

The outcome of courses and programs in global design should be students prepared to work in the global economy and motivated to do so. Finding metrics that measure our success in doing this is not easy. We have proposed previously using a stakeholder assessment model [22], but that is only a partial solution. However, the model is useful in the short term for program development. Two other methodologies would be an *a priori* model whereby we designed the education on knowledge gained from researching global design practices, and a performance model whereby we track the consequent professional performance of the students. Of all these methods, we think that the *a priori* research-based approach is most needed in the long run.

References

[1] Ghadar, F., and E.R. Peterson, *Global Tectonics: Underlying Trends Shaping the Future of Business*, release date June 2005.

[2] Peterson, E.R., "Seven Revolutions: Looking out to the year 2025 and the major forces shaping the world," available at http://www.csis.org/7revs/index.htm.

[3] *The Engineer of 2020: Visions of Engineering in the New Century*, The National Academies Press, 2004.

[4] "An emerging and critical problem of the science and engineering labor force: A companion to Science and Engineering Indicators 2004," National Science Board, 2004, available at http://www.nsf.gov/sbe/srs/nsb0407/start.htm.

[5] Mote, D., testimony to the Senate Foreign Relations Committee on 6 October 2004, available at http://www.president.umd.edu/ForeignRelationsTestimony,

[6] McCarthy, J.C., C.F. Ross, W. Martorelli, C. Mines, A. Brown, "Near-term growth of offshoring accelerating: Resizing U.S. services jobs going offshore," report from Forrester, Inc., 2004.

[7] Design Council, "The Impact of Design on Stock Market Performance: An Analysis of UK Quoted Companies 1994–2003," February 2004, available at http://www.designcouncil.org.uk/resources/assets/assets/pdf/Research/Impact%20of%20Design%20on%20Stock%20Market%20Performance%20February%202004.pdf. Also go to http://www.designcouncil.org.uk/ and see their report on 1500 companies in Design In Britain 2004–5.

[8] Schwartz, E.I. "Sparking the Fire of Invention," *Technology Review.com*, May 2004.

[9] "Global Invention Map," *Technology Review.com*, May 2004.

[10] Devon, R., S.G. Bilén, A. de Pennington, A. McKay, P. Serrafero, and J. Sánchez Sierra, "Integrated design: What knowledge is of most worth in engineering design education?" *International Journal of Engineering Education*, vol. 20, no. 3, 2004, pp. 424–432.

[11] Pangborn, R.N., "What are our students (and graduates) doing? A Longitudinal Analysis," presentation to the Faculty Advisory Board, Penn State University, April 2002.

[12] Price, A., and J. Sloane, "Global designs: Tough challenges for acquirers," *Mergers and Acquisitions*, vol. 32, no. 6, May/Jun 1998, pp. 50–55.

[13] "Design alliance goes global," *Building Design & Construction*, vol. 39, no. 5, May 1998, p. 16.

[14] Jarvenpaa, S.L., and D.E. Leidner, "Communication and trust in global virtual teams" *Journal of Computer-Mediated Communication*, vol. 3, no. 4, 1998.

[15] Braham, J., "Global design is here, but...," Machine Design, vol. 65, no. 6, 26 March 1993, pp. 32–9.

[16] Gottschalk, M.A., J. Lewis, and R. DeMeis, "Engineers strive for world-class design," *Design News*, vol. 52, no. 22, 17 November 1997, pp. 75–87.

[17] Richard, O.C., T.A. Cochan, and A. McMillan–Capehart, "The impact of visible diversity on organizational effectiveness: Disclosing the contents in Pandora's black box," *Journal of Business and Management*, vol. 8, no. 3, pp. 265–92, Summer 2002.

[18] Devon, R.F., A. de Pennington, and A. McKay, "A Consortium for Global Engineering Design," *Canadian Design Engineering Network (CDEN) Inaugural Conference Proceedings*, Montreal 2004.

[19] More information on the Engineering Design Program at Penn State may be found at http://cede.psu.edu/ed.

[20] More information on the Prestige Consortium may be found at http://prestige.psu.edu.

[21] The report may been see at http://prestige.psu.edu/Nomads2004/.

[22] Bilén, S.G., R.F. Devon, M.R. Henderson, and H. Nguyen. "Global Approaches to Teaching Global Design: Stakeholders, Programmes, and Assessments," *World Transactions on Engineering and Technology Education*, vol. 3, no. 1, 2004, pp. 29–34.

Sven G. Bilén
The Pennsylvania State University
Engineering Design Program
School of Engineering Design, Technology, and Professional Programs
213N Hammond Building
University Park, PA 16802
USA
Phone: +1 814 863-1526
Fax: +1 814 863-7229
E-mail: sbilen@psu.edu