Global change and the management of engineering education

Richard Devon & Julia Liu

Pennsylvania State University
University Park, United States of America

ABSTRACT: Engineering expertise is deployed through a series of skills that are a function of the social and economic milieu of engineering. This essay seeks to identify how this milieu is changing and how the changes affect both the nature of the contextual skill requirements of engineers and the institutions of higher education, which provide the first acquisition of these skills. In particular, the consequent issues for pedagogy and for managing continuous change, including curricula change, in engineering education are addressed. While global in scope, the view presented is from a USA perspective.

INTRODUCTION

The world is changing in fundamental ways, and, as educators, we have to be responsive to these changes. Despite some questioning of globalisation after the September 2001 attacks in the USA, it is likely that more global interdependence will emerge in the new anti-terrorism culture, not less [1]. Driven by information technology, and by an economic culture that would leave no resource unutilised, the world will continue to become more integrated. Perhaps a billion or so people are well served, and more badly served, by the global economy, but fewer and fewer remain unaffected.

The nature of globalisation varies by country. The USA, for example, tends to be very high on Internet use and political engagement (membership in international organisations), while relatively low on personal contact (such as travel and phone) and economic integration (trade foreign investment). Ireland is exactly the opposite [1]. France and Australia lead on the measure for political engagement.

We are moving rapidly into a networked society in which old and familiar institutions are losing their power, most notably the nation-state itself. Some governments are still very significant players in the global economy [2]. However, most nation-states are gradually losing the ability to inspire, to tax, and to control their domestic economy [3]. In a pattern that has grown steadily over the last few decades, of the 100 largest economies in the world in the year 2000, 51 were global corporations, and only 49 were countries, according to the Global Policy Forum [4].

Even at the local level, we are now urged to connect directly with the global economy [5]. For example, in State College, a small rural Pennsylvania community, the largest industry, Corning Asahi, is an American-Japanese alliance that manufactures glass TV screens according to ISO quality control standards because their customers worldwide expect it. This directly affected an engineering project that had been supplied to Pennsylvania State University in University Park, USA, by Corning Asahi in the mid-1990s. Similarly, the workplace and the shopping mall are, like the financial world, now global [6].

The best industrial practice that must be met now means the best anywhere in the world [7][8]. Thus, if there are salient features of the global workplace that engineers should know, it follows that their education should anticipate them.

From the mid-1980s to the mid-1990s, the global stock of direct foreign investment rose four-fold [9]. Further, the economy is more and more based on information and services [3][10]. Almost all the major corporations have dispersed their operations around the world, and intra-corporate transactions explain much of the trade gap of the USA, making that figure increasingly meaningless [2][10]. This means that inter-corporate, rather than international, competition is increasingly the critical dynamic and in the economic arena the USA is less of the superpower that it is in military affairs. In the 1960s, 304 of the top 500 multinationals in the world were based in the USA; by 1993 that figure was down to 157 [4], and down further to 153 by 1996 [11]. It follows that more and more of the engineering jobs that are offered by the top 500 companies will be with foreign-owned corporations.

Students with knowledge of, and experience in, the global economy will be more competitive. Hence foreign cooperatives and internships and foreign languages skills are increasingly going to offer a competitive edge.

While the pursuit of profit and the protection of capital still rule the corporate world, the means is now described as:

> *the increasingly efficient connection of network nexuses* …[because] *the world is becoming a gigantic stock exchange of information that never closes* [3].

Yet the whole world may not be in the picture described by Guehenno, since over 95% of the world's Internet hosts are estimated to be in countries of the Organization for Economic Cooperation and Development (OECD) [1].

Indeed, of several tensions in this new world, inequality between nations is certainly one. One outcome of this is that the make up of the graduate student body and the faculty in colleges of engineering, where most graduate students and around half of the faculty are foreign born and most of them come from the developing worlds of West, South or East Asia, and, more recently, from countries that emerged from the break up of the Soviet Union. This *brain drain* occurs mainly from countries whose educational resources are presently far better than their economic resources and it represents a huge benefit to the recipient countries.

Conversely, even with this international resource base, colleges of engineering in the USA have been slow to engage in programmes to help prepare their students for work in the global economy. Things may be changing. In autumn 2001, a survey was made of the interest and activity levels in international education programmes of about 400 engineering faculty at the campuses of Penn State. Of those responding, about 100 said that they wanted to be kept informed of events and programmes relevant to international engineering education. This is thought to be an increase of an order of magnitude over the last five years by those of us active in the area over the last decade.

Another tension in the global economy is between the increasingly autonomous and efficient peripheral units, and the centre, which has a more and more complex task of coordination and control. The proliferation of consortia among universities both nationally and internationally, while encouraged by the participating universities, inevitably leads to more external drivers of policy in these universities.

Further, even though major industries are now typically global in their operations, getting connected to the international sectors of corporations is often hard because of the decentralisation that has occurred within the corporations. Thus, expanding from a domestic cooperative programme to an international cooperative programme using the same industry partners will not follow unless the corporations make a special effort to link sectors that are very separate at the moment. By way of a summary, Table 1 includes some of the salient features of this new world.

INFORMATION TECHNOLOGY AND THE RESPONSIBILITIES OF THE UNIVERSITY

The Internet and other forms of information technology have had a huge impact on higher education [12]. However, although information technology releases us from the constraints of time and place, it does not release us from the need to perform the traditional functions of higher education: the public preservation, validation, development and dissemination of knowledge. How these functions will be performed in the future is not clear, but information technology has not yet provided a full alternative.

Table 1: Features of a global economy.

People who are increasingly interconnected, interdependent, and geographically mobile.
Information as the new currency.
Decentralisation of power, reduction of hierarchy, and increasing complexity.
The globalisation of economy, workplace and culture, including international standards (ISO).
A weakening of nation-states and a strengthening of multinational corporations, which are increasingly decentralised.
The functionalising of relationships – the extent to which we know and relate to people only as an extension of our work.
The diversification of relationships as multicultural and multinational; teams become the norm.
Continuous change in technology and organisational structures.

To date, information technology is transforming the dissemination function of knowledge and augmenting the development and preservation functions of knowledge. It is doing little for the validation function and it has an alarming tendency to impermanence as Web sites come and go or slide out of date.

A public community of scholars is necessary to keep the functions of the university from jeopardy. The increasing interest of universities in scrambling for a share of the perceived global market in educational services is problematic in this regard, particularly since it is still very capital and labour intensive and depletes resources invested in the traditional activities of residential teaching and research.

PEDAGOGICAL ISSUES FOR THE ENGINEERING CURRICULUM

While basic science and engineering principles still need to be acquired, the contextual skills required to affect a delivery system for the underlying expertise must be in tune with the times. Some objectives for preparing students for the global economy are proposed here.

Information Technology Skills

The students must learn the latest in information technology because the flow of information defines the life and the health of the workplace, from the self-employed to multinational corporations. In many ways, information technology is increasing the power of the self-employed and small-scale enterprises, but only if it is understood, affordable and used. It also allows for virtual teams with members from different locations and even different countries. With well-spaced, global participation, a project team can work continuously in either education or industry.

Active Learning

The only constant is change. As educators, we must prepare students to handle change. For example, a recent survey of 12,000 managers in six countries found that 32-71% had experienced major company restructuring in the previous two years [5][13]. The figure for the USA was 59% [5].

The skills on the job, and the information required to do the job, are changing far more rapidly than before. The laws of thermodynamics have not changed, but technologies based on information, as more and more are, keep changing. The growing role of skill obsolescence means that students must learn how to learn. Indeed, there has been much interest in the need for organisations themselves to be *learning* institutions [14].

Design

The best preparation for handling any change may be teaching students design - even if they are not engineering students. They should learn the processes of problem clarification, the use of democratic information flows, the identification of stakeholders, the creation of product design and development teams, the creative process of generating options, the weighing of tradeoffs in technology assessment and the development and testing of prototypes [15]. Interestingly, design itself has recently seen the emergence of a common approach for the first time [16-18].

Interdisciplinarity

Universities and colleges are characterised by specialisation with rather weak attempts to overcome the effects of this specialisation through general education requirements and integrative programmes, eg science, technology and society. However, what we have not done well by relying on values and reason, we might do better by necessity. The world beyond the university must normally deal with interdisciplinary problems such as design. As education becomes more closely articulated with its consequent uses, there will be more interdisciplinarity in the curriculum.

The new pedagogy is Problem-Based Learning (PBL) and it requires and promotes interdisciplinarity. In engineering, it is called project or product-based learning [19]. Research shows that on measures of complex interdisciplinary thinking, which represent professional behaviour well, students who have PBL experiences do better than those in traditional curricula [20]. More time needs to be spent teaching the interdisciplinary subject of project management in engineering education. Finally, interdisciplinarity must include global learning from international standards to cultures, government polices and industry practices in other countries.

Collaboration

Obviously, engineers work in teams and preparing them to do this well is very important. Active learning and teamwork will provide good experiences in collaboration. Diverse teams can be more creative and work better in the global economy [19][21]. To make diverse teams, or any teams, work well, the learning of conflict resolution skills is suggested, such as negotiation, mediation and cross-cultural awareness (race, gender, cross-national) [22-24].

Collaboration includes the development of foreign language skills and acquiring international experiences to aid working with people from other countries and cultures. The latter can be expensive but a low cost alternative approach can be achieved by using information technology.

Since autumn 1997, Penn State has used joint US and French student teams to tackle design problems from industry in the honours section of the introductory design course [25][26]. Both American and French industries have supplied problems. Communications are by ISDN and TCP/IP, computer-based video-conferencing in virtual office platforms (*NetMeeting*, *PicureTel 550*), e-mail, phone, fax and the World Wide Web (WWW). Students at Penn State whose teams rank highly get an opportunity for a tour of French industries in the following summer.

There are usually some logistical and technological problems that take time to resolve in running these teams, but language is not much of an issue and all teams successfully create bilingual sites for the design solution [25][27]. Student translators, translation software and the native language speakers in each team are utilised. In fact, Penn State is developing a four country, trilingual, multi-university consortium, and will try multi-point teams in the future.

Penn State is currently exploring collaborative design tools such as Alibre Design. Alibre allows a team that may be globally dispersed to use a common design space by downloading client software. The drawings may be imported with IGES or SAT formats or constructed within the design space. Collaborative tools include chat, voice and video, and a display of current team members logged on with their privileges shown (control, editing power, watch-only). There is a clear archival system for drawing notes and revisions.

Many other CAD packages also have collaborative tools such as *Ideas* and *Solid Edge*. These collaborative CAD spaces allow students to communicate even though they may be learning and creating designs in different CAD software.

MANAGING CURRICULA CHANGE

Faced with a changing world and the need to change to compete or even to keep up, how does one get there from here? The usual constraints of time, money and culture apply. Cultural change will come with technological change as it usually does: not easily, not cheaply, but inevitably. The most important additional constraint is the need to put in place a new dynamic system to replace the old static system.

Moving from A to B cannot be done in the usual sense, because B now has to be a system that will handle continuous change (C, D, E, F….). And, only considering the case of curricula change, Table 2 shows some of the processes that must be done continuously.

How can all of these changes be managed? Five policies are suggested that may be helpful: delegation, collaboration, faster and better decision-making, cost minimisation, and a search for the most enduring resources and practices.

Delegation

The biggest constraints have to do with time and expertise. Most faculty members do not have the time to become fully expert in the use of the new technologies on their own, nor can they take on the service work for the department if they do acquire this expertise without jeopardising their careers. The answer is clearly delegation, but delegation means finding people who have the skills, or the time to learn them, and who can be hired affordably.

Table 2: Necessary continuous changes.

Deciding what types of supporting tools are needed.
Identifying technologies that meet curricula objectives.
Assessing and selecting a new technology.
Installing new technology.
Providing training and resources for new technology.
Changing curriculum to accommodate new technology.
Testing new curricula changes.
Implementing new curricula changes.
Assessing new technology and curricula changes.
Integrating the technology into existing maintenance procedures.
Getting it done before the next round of changes.

Penn State increasingly uses undergraduate students, who are well versed in, and/or well motivated towards learning, information technology. The extrinsic rewards needed for learning these skills are modest, and the resources are available online. There are tradeoffs, such as the need to continuously recruit and train and to juggle work and class schedules. The student solution costs far less than the faculty solution and it is far easier to implement. The equivalent of four undergraduates are used for every full-time instructor. The students are very well motivated and not distracted by publishing and administrative demands. Further, it is excellent education for the students and will get them jobs.

Collaboration

Intra-institutional collaboration, while important, is now giving way increasingly to inter-institutional collaborations. In the USA, the National Science Foundation (NSF) has promoted inter-institutional collaboration through its coalitions since 1990, and the Department of Education has promoted international consortia through its FIPSE programme.

The changes brought about by information technology occur, or should occur, at most schools of engineering. Why have hundreds of competing teams inventing the same wheel? Taking a lesson from collaborative design, it could be assumed that those who collaborate will fare better than those who do not. Some development costs may be shared and shared experience and expertise will enhance quality, speed the *time to market* and reduce frustrations. The other benefits of collaborations include enhancing the legitimacy of the changes and making it easier to persuade the faculty and administration at each institution.

A critical area for collaboration is with industry. Getting advice from design engineers in industry is very valuable. These engineers can now be brought into the classroom to interact with the students through video-conferencing. However, there is some difficulty in finding engineers who have the latest information technology and who are not confined within a secure computing environment. It would help if industry would make more of an effort to get around this restriction and get their experience into the classroom using information technology without even leaving their offices.

Faster and Better Decision-Making

Given that so much time is spent implementing changes, good decisions are needed about what to do and fast ways of making those decisions. A better appreciation of technology assessment is required and ways to do it quickly. We have already learned, for example, that technology is needed that is compatible, powerful, very relevant to our needs, cheap, easy to learn and maintain, and with a relatively long useful life.

Quality control in the delivery of the basic content (both knowledge and skills) is critical. Stakeholders should be included in order to provide diverse and relevant views quickly. The tradeoffs and weighting can be informed by the judgments of a team that is based at several different institutions. Ironically, both success and failure are devalued by rapid continuous change since we keep moving on regardless of the outcomes from the last change. So better decision-making is hard to do in a culture where change itself is so highly valued.

Carol Steiner has argued that the educator's dilemma is to teach engineering certainty, while also creating students irreverent (authentic) enough to step outside the *engineer's paradigm* and innovate [28]. Yet innovation is becoming the new orthodoxy. And, if we also want to teach ethics in engineering, as is done in the USA, we will have to deal with the questions *design for what?* and *design for whom?*

Cost Minimisation

Many information technologies do not stay around very long. Having a computer for four years, or software for two years, is being very economical. The amortisation period is very short, so one should always look for the cheapest technology that will meet specific needs. It must also be quick to learn, already tested at someone else's expense and cheap and easy to maintain – often overlooked in the acquisition process.

Very high-tech, high priced technology should always be bought by someone else. It will be obsolete in a few years and the large financial investment will make it very hard for the user to abandon it. This will leave the user both in debt and out-of-date.

The Most Enduring Skills and Practices

In a volatile society, the most important skills and software are those that can be adapted and can remain despite the shifting dynamics. This comes down to keeping the rate of change manageable.

There is little to say about this except in hindsight. For example, between 1984 and 1991, the first-year course at Penn State went through four quite different CAD packages. The fourth, a solid modelling package, *Silver Screen*, lasted for seven years, including six upgrades. This was a good run for a CAD platform. *IronCAD* is now in use in the introductory course, but there is continuous pressure from CAD vendors as they drop prices to get into the pre-professional world of engineering education. As the cost becomes less, the learning curve and the maintenance costs become more significant.

CONCLUSION

Higher education will follow the general trends of decentralisation with global connectivity, continuous change and the increasing use of information technology. The adoption of cost effective information technologies, the use of active and collaborative learning and an emphasis on design are recommended. The networking capabilities of information technology should be used to improve communications with industry and with other societal institutions, and to enhance the international quality of the education process.

The driver in all this should still be university-based education, rather than distance education. Distance education should be an extension of the classroom, not a commodification of it. University-industry relations also need to accommodate the new reality with new international connections for universities.

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