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The renaissance engineer: educating engineers in a post-9/11 world*

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Technology that fuels the economy and adds to the quality of life can also bring with it unexpected complexities. The events of 11 September bring into sharp relief some of the vulnerabilities that exist in the world, and also challenge us to re-examine the role of engineers in society. To date, the traditional responsibilities of the engineering communities in preventing future catastrophes have been defined purely in terms of technological advances. However, it is clear that engineering must go beyond pure technology to consider also the causes of vulnerabilities and examine if and how engineering can address matters that are often embedded in the social and economic fabric of society. Moreover, engineers must go beyond being technical experts who understand and consider social, financial and political factors in their work, and become leaders in all arenas of society. These expectations call for *renaissance engineers* and the need for a renaissance in engineering education. Recommendations to cultivate a new generation of renaissance engineers centre on recognition of individual talent and customizing education accordingly.

1. Introduction

The world as we know it changed profoundly on 11 September 2001. In the wake of the events of that day and those that followed, our sense of personal security has given way to the grim knowledge that deadly terrorism can be delivered at any time by free agents somewhere, anywhere, in the world. The result is nothing less than a new world-view. As citizens of this new world, we must adapt, confront our fears and continue to lead our lives; and as engineers and educators, we must ask: How do the events of 11 September impact our role and the role of engineering in society? And how can we best prepare engineers for the challenges ahead?

To answer these questions, we begin by looking at history, and in particular the Renaissance in Europe. The 1400 s was a time of immense change and political upheaval, a rebirth and awakening from the medieval world-view to a new world-view that embraced the promise of new ideas and new technologies. The forces at work were many: shifts in political power; new trade routes that brought the East to the West; the printing press, a technological marvel of the time, that accelerated the flow of information throughout Europe; and innovative thinkers, whose contributions led to a flourishing of the arts and sciences.

In many ways, the Renaissance symbolized the emergence of the individual. Consider Florence, the birthplace of the Renaissance, 600 years ago. The most significant agents of change in Florence at that time were imaginative geniuses such as

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Galileo with his idea that perhaps the sun, not the earth, was the centre of the universe. Michelangelo, whose dazzling conception of the beauty and promise of the individual is embodied in his David, also imagined and engineered such architecture as St Peter's vast basilica in Rome. Machiavelli made enormous contributions to the new world-view by analysing the channels of power flowing through society; and of course, Leonardo da Vinci made some of his most ambitious investigations in Florence, including sketches of flying machines, human anatomy and military defence projects that Professor Galuzzi (2001) eloquently describes in his book. Individual such as da Vinci who epitomized the time were broad thinkers whose vision encompassed the sciences, the arts and the political forces of the day.

As in the 1400 s, our time is one in which the individual prevails, empowered by technology to access instantly a world-wide forum for the exchange of new ideas and new information. Technology and the globalization that it engenders have fuelled economies, increased the quality of life for many and encouraged the entrepreneurial spirit. However, while the genesis of much positive change, today's technological advances also bring with them complexities that are often unintended and unplanned. Many find it unsettling, for example, that a mere handful of terrorists used commonly-available technology to accomplish their goals. Using cell phones and Internet communications, wire transferring funds—even flying commercial planes—are all tools readily available to many people in today's society. In short, the events of 11 September combined the unintended consequences of technology with planned misuse.

2. Technology and globalization: the two-edged sword

Clearly, technology, particularly in the global arena, is a two-edged sword; and because engineers are the first to create, understand and use technology, it is imperative that we also understand its by-products and their relationship to globalization.

A brief look at the idea of vulnerabilities is helpful in understanding the role of technological innovations in society. Vulnerabilities come from two sources: natural and human-induced. Natural vulnerabilities include earthquakes, floods, drought, natural fires and infectious diseases such as AIDS. Human-induced vulnerabilities come in two types, the first of which is inadvertent vulnerabilities that result either from carelessness or from negligence. Examples include such incidents as the Chernobyl and Three Mile Island disasters, or those that result from ignorance and haste, such as the use of asbestos, DDT and the like.

The second type of human-induced vulnerabilities are the malevolent ones. Malevolent disasters can be caused by states, usually in the form of wars, and may include use of biochemical weapons such as Agent Orange and anthrax. Malevolent disasters can also originate from individuals or groups, such as the Unabomber or those who destroy hospital records, contaminate Tylenol pills with cyanide, release Sarin in Tokyo subways, bomb Oklahoma City, or use planes as weapons as in New York and Washington, DC. Such malevolent actions usually have shorter time constants for planning and execution.

Vulnerabilities, both natural and human-induced, have always been part of the human condition. What is new, however, is the malevolent use of weapons of mass destruction aimed at unsuspecting civilian populations, as in 11 September and the mailing of anthrax to political leaders in the USA. What distinguishes modern-day vulnerabilities from earlier ones is ready access to technology that enables a person or a small group of individuals essentially to act as a nation state and attack civilian populations.

It is clear that advances in technology come at a price, and today's engineers, who create and implement technology, must understand that price, reflect on its implications and safeguard against the misuse of technology.

3. The role of engineering in today's world

As Florence 600 years ago looked to its engineers, scientists, artists and scholars for insight into new challenges, society today is looking to engineers and leaders for answers and ideas. The engineering community must rise to the occasion and demonstrate leadership in providing answers about the role of technology and the engineer in today's world.

Today, being a 'technical' engineer who just develops technology is no longer enough. Modern engineers must understand globalization and its implications, i.e. 'the integration of markets, nation-states and technologies to a degree never witnessed before—in a way that is enabling individuals, corporations, and nation-states farther, faster, deeper, cheaper than ever before. This process of globalization is also producing a powerful backlash from those brutalized or left behind' (Friedman 2000). Engineers need to make sure that their profession is not left behind.

We shall always have vulnerabilities because to be human is to be vulnerable. Attempting to eliminate vulnerabilities completely can dehumanize us. However, a modern engineer should be able to balance the vulnerabilities created as by-products of technology and globalization with the gains both afford us, without compromising the well-being of society and humanity. It is essential for the modern engineer to understand and appreciate this subtle balance.

A modern engineer must also reach beyond pure technology to consider the causes of vulnerabilities as well as relevant social, economic and cultural issues. A report issued by the National Research Council (2002) describes a systems approach to counter terrorism that cites as input to the system such issues as 'unfavorable socioeconomic conditions, geopolitical considerations, cultural conflicts and racial and religious issues'. Such a systems approach considers all aspects of terrorism, from its causes to methods of maintaining security. The apparent role delegated to engineers is traditional and related to technology. Clearly, engineering must respond by contributing to technology to assist in prevention, protection and interdiction, and in managing the consequences of disasters. However, the engineer's role should not be limited to dealing exclusively with traditional technical matters. Engineers also have a responsibility to consider the causes of and conditions that give rise to vulnerabilities and malevolence.

The need for considering effects that are seemingly removed from the problem at hand is not unique to engineering. According to the *Economist*, 'More than two centuries ago, Adam Smith explained the benefits of the division of labor. It is, he suggested, more efficient for each worker to focus on one task than for each to perform every task himself. Economists have taken this message rather too literally to heart over the past three decades, delving into narrow specialties, abstract theories and exotic mathematics'. Only in recent years have some economists begun to adjust economic forecasts to reflect the true costs of environmental degradation as well as of traffic congestion and crime. Similarly, engineering communities have been discussing for some time the need for incorporating business and the economics of engineering in the curricula. If we are to learn from the experience of the economists, perhaps we should also consider matters that are rooted in economic, geopolitical and social issues.

In short, modern-day vulnerabilities and the complexities brought on by technology and globalization lie at the interface of not only technical, but also social, political and economic aspects of society. In a post-9/11 world, engineers cannot afford to isolate themselves and focus only on 'technical' matters to the exclusion of the broader consequences of their actions.

4. The renaissance engineer

In times of social stability, it is the specialist who best contributes to society by driving deeper into a given discipline. However, times of great flux call for those who can cross disciplines, who can see and understand the larger picture. Just as the renaissance individual of 600 years ago responded to immense change by cultivating learning in the arts, sciences and letters, today's engineer must study politics, world history and economics in addition to science and engineering. It is not enough to learn about technology—one must now strive to understand technology's role in a changed world. Today, technical problem-solving must include the context within which the problems exist. The complete context, or design space, includes social, economic and policy-related consequences of engineering.

Building on our model of the modern engineer, what must emerge post-9/11 is the renaissance engineer. The renaissance engineer is a 'globalist', one who is aware of potential effects of globalization and technology—and the price with which each comes. The renaissance engineer must understand both the known and unknown risks associated with global technology and safeguard against them.

To address vulnerabilities and their causes better and to anticipate and respond to the needs of society more effectively, the renaissance engineer must be able to work with complex systems, for the modern world is certainly complicated; and because today's vulnerabilities are tightly coupled with irrationality and non-linearities, the renaissance engineer should be able to deal with predicaments, not just problems.

Engineering is a creative enterprise, and the renaissance engineer must be a creative thinker and strategist. As such, he or she understands human behaviour and needs as well the impact of technology on those behaviours and needs. The renaissance engineer who understands society can design for the needs of society by anticipating what those needs will be.

Professor Galluzzi (2001) points out in his book that 'Early Renaissance artists were routinely involved in activities that would now be defined as engineering'. They include Brunelleschi, Taccola, di Giorgio and, of course, da Vinci. One may add to this list Machiavelli as perhaps the first social engineer. That was an era of artist–engineer. This is the era of leader-engineer.

Closer to our time, an example of a leader-engineer is Benjamin Franklin, a printer and writer, scientist and politician, who created many means of using new technologies to improve people's lives. Benjamin Franklin devoted his life to civic causes and believed that people's differences could be healed with adequate understanding and resolve. In fact, his ideas of higher education led to the University of Pennsylvania, a novelty at the time in colonial America.

5. Educating the renaissance engineer

Can today's educational system develop renaissance engineers? Perhaps a better question is: What can educators do to foster the emergence of renaissance engineers?

In my view, the best approach to attracting and educating renaissance engineers is first to value individuality. If one subscribes to the notion that individuals come with a combination of different intelligences (Gardner 1993), then we realize that students who enter universities also come with different talents, interests and intelligences. Traditional engineering education, however, emphasizes two of these and *de facto* suppresses the others. I suggest that we customize the education we offer students in order to take advantage of their diverse innate talents. Customizing education according to talents and needs of students can be accomplished by providing flexible learning opportunities, a fundamental change in the philosophy of engineering education that requires students to take many courses to qualify as an engineer. It is important to allow students, our future engineers, to have a role in this complex process of preparing for their future (Akay 2003).

Secondly, to prepare renaissance engineers to deal effectively with modern vulnerabilities, we need to bring 'security issues' into the curriculum on a system-wide level. Wherever possible, technologies studied or created need to be analysed with respect to misuse, or malevolent abuse. We also need to look at the sources of global terrorism in order to understand better the anger behind it and how to safeguard ourselves from its threat. As Ben Franklin suggested, technology designed to improve lives must be developed through intelligent analysis of current societal problems.

A very critical task relates to the education of PhD students. In the USA it is said that one-third of engineering PhD graduates take positions in the academe and two-thirds join industry. However, while universities often prepare PhD students to conduct research, this preparation does not necessarily incorporate the needs of academe or industry. We must broaden our scope and the scope of our graduate students.

Educators are not alone, nor should they be, in the enterprise of engineering education. Government agencies, through resources that they control, can have a direct influence on the development of renaissance engineers. Industry also has a stake in the education of engineers. It is in the best interest of industry to cease viewing engineers as a commodity, to recognize their true value and to assume its role in what amounts to a lifetime education of engineers. Finally, professional societies need to understand that society is changing at a much faster rate than they are. They need to embrace the notion that they themselves should undergo a renaissance of sorts in order truly to assist practising engineers.

6. Closing remarks

Education can have a tremendous role in addressing the challenges and issues of a post-9/11 world. By accepting this challenge, we can all contribute to a safer, more promising future. However, it is also clear that no matter what engineers do, there will always be vulnerabilities, and always new methods, targets and tragedies will follow. What is an engineer to do?

Sisyphus, the mythical figure that was also Albert Camus's archetypal existential hero and metaphor for modern man, provides a case. Sisyphus was condemned by the gods forever to roll a huge stone up a mountain, only to see it fall back to the bottom each time he reached the summit. However, for Sisyphus, the struggle itself toward the heights was enough to fill his heart (Florman 1976).

We realize that, as engineers and engineering educators, we shall never completely eradicate vulnerabilities of the world. But, like Sisyphus, the inventions, new designs, new considerations, the struggle itself will be enough to fill the heart of an engineer; and that is the mandate of the renaissance engineer.

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