

The Engineer in the Information Age

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Introduction

When looking at technology, we seem to see only machinery, not the people behind it. That filter determines our attitude towards technology and explains our neglect of the process of its creation. We seek to understand the tree without examining its roots.

Technology is “the application of scientific knowledge to the practical aims of human life or, as it is sometimes phrased, to the change and manipulation of the human environment”. As such, it has played a crucial role in human survival, allowing a physically weak species to marshal natural laws and resources in its defence. Since the harnessing of plant growth in agriculture, the taming of fire and the invention of writing, the fruits of technology have surrounded and transformed us. The cumulative effect of technological development has brought us to a point where technology is intertwined with every aspect of our lives – yet we are still not entirely comfortable with it.

There is passivity in modern society towards technology. While new products are continually brought to our attention through advertising, the degree of control most of us exercise is only in buying this or that product and, at most, in telling our friends about it. This is perhaps comparable with the degree of control a couch potato exercises through his remote over the content that networks beam at him.

However, there is a segment of society that actually makes technology, which trolls the journals of science for new ideas and looks at the reactions of consumers to old products in order to design new ones. These people also have the responsibility of keeping the old technology running and are the ones you call when products don't work as they should. These are, of course, the engineers who belong to a “profession in which a knowledge of the mathematical and natural sciences, gained by study, experience and practice, is applied with judgment to develop ways to utilise, economically, the materials and forces of nature

for the benefit of mankind".¹ Going by this definition, the term engineer must equally apply to practitioners of 'old' technologies -- the farmers, carpenters, architects and plumbers -- as it does to geneticists and computer programmers.

The Gap between Importance and Perception

Oblique evidence of the supreme importance of engineers in recent times is available from the Soviet Union. Almost the entire generation of Soviet leaders that followed Stalin were engineers -- including Krushchev, Kosygin, Brezhnev and Yeltsin. The probable reason for this was that while Stalin had little hesitation in wiping out everyone else, he must have appreciated that there was no way he could beat the Nazis, or compete with the West, without engineers. When he died these were the only people left in any sort of leadership positions.

A Martian reading of this might imagine that engineers are the stars of a civilisation that is totally dependent on technology. Yet nothing would be further from the truth! Like the craftsmen who created medieval architectural and other masterpieces, most engineers remain anonymous, even the brilliantly successful ones.

How many people could identify the inventors of the digital computer (John Mauchly and J. Presper Eckert), a device whose importance in modern life is second to none? Alfred Nobel was himself an engineer par excellence. His invention, dynamite, is still widely in use in mining and construction.² That even he did not see fit to institute a Nobel Prize for engineering is typical of the modesty of the profession. Perhaps the best example of society's lack of attention to engineers, however, is the case of Claude Shannon whom few outside the profession have even heard of. This genius discovered that Boolean algebra, an area of mathematics thought to have no practical use, was perfectly suited to the design of digital circuits. H. H. Goldstine, in his book *The Computer from Pascal to Von Neumann*, called this work "a landmark in that it helped to change digital circuit design from an art to a science". In 1981 Professor Irving Reed, speaking at the International Symposium on Information Theory in Brighton, England, said: "It was thirty-four years ago, in 1948, that Professor Claude E. Shannon first published his uniquely original paper, "A Mathematical Theory of Communication", in the *Bell System Technical Journal*. Few other works of this century have had greater impact on science and engineering. By this landmark paper and his several subsequent papers on information theory he has altered most profoundly all aspects of communication theory and practice". This paper has justifiably been called "the Magna Carta of the information age".

Shannon's work on information theory has also had significant impact on fields outside of communications -- including linguistics, psychology, economics, biology, even the arts. Robert W. Lucky, executive director of research at AT&T Bell Laboratories, called his work the greatest "in the annals of technological thought", while IBM Fellow Rolf W. Landauer equated his "pioneering insight" with Einstein's. Claude Shannon died as recently as February 24, 2001, but the Internet, inconceivable in the absence of his insights, barely noticed.³

If people pay no regard to those who make technology, nor make any effort to understand them, they will find it hard to appreciate the logic of the direction it takes -- for the inventor and the invention resemble each other. If the products of technology often seem lacklustre and unimaginative, maybe this is a reflection of a similar lacunae in most engi-

neers. We can also take the analysis one level upstream. To understand why engineers turn out the way they do, one must look closer at how they, in turn, are made through life in an engineering college.

The Deficient Education of Engineers

The manner in which engineering is taught is incredibly authoritarian and dull. The reason for this is not hard to find. As pointed out by Peter Senge and others, our modern education system was born during the Industrial Revolution, which faced a severe shortage of trained personnel. At the time, industrialists made a fortune by taking manufacturing out of the community and locating it in a new kind of space called a factory. Faced with a shortage of people skilled in manning these factories, the owners applied their tried and tested formula once again: they took education out of the community and made it the responsibility of a new kind of factory called a school. Indeed, our schools are organised along the same principles as assembly lines: students are like parts moving in lockstep from one class to the next, while teachers are like machines that impart education, within a highly authoritarian system. If a student cannot successfully pass the requisite tests, he is thrown out, not unlike a part that has failed quality control.

According to Senge, "while the assembly line school system dramatically increased educational output, it also created many of the most intractable problems with which students, teachers and parents struggle to this day. It operationally defined smart kids and dumb kids. Those who did not learn at the speed of the assembly line either fell off or were forced to struggle continually to keep pace; they were labelled 'slow' or, in today's more fashionable jargon, 'learning disabled'. It established uniformity of product and process as norms and thereby naively assumed that all children learn in the same way. It made educators into controllers and inspectors, thereby transforming the traditional mentor-mentee relationship and establishing teacher-centred rather than learner-centred learning... The assembly line education system is now under stress. Its products are no longer judged adequate by society. Its productivity is questioned. And it is responding in the only way it knows how: by doing what it has always done but harder".⁴

Is it any wonder that a system which discards human beings as scrap produces so many terrorists and criminals? Those who survive it are almost brainwashed into believing that having an opinion about anything outside of their narrow areas of technical competence is inadvisable. The syllabus pounded into them is needlessly voluminous and difficult, of which a practicing engineer only actually ever uses a tiny fraction. Teachers typically have almost no industrial experience, nor do students have any regular interaction with industry. Could anyone imagine a medical school without an attached hospital, where the teachers have almost never seen a patient?

It hardly comes as a surprise, therefore, that this profession attracts few women. Even among the men there is a very high proportion of, to say the least, poor communicators. Yet, these poorly equipped and trained people are the ones entrusted with running critical industrial establishments, and can be held partially responsible for such disasters as the Union Carbide plant in Bhopal and the nuclear reactors in Chernobyl and Three Mile Island.

The Gap Between the Humanities and Engineering

There is much that can be done to improve this situation. For a start, what is clearly needed for a better understanding of technology and its dynamics, is greater interaction between the engineering and the humanities departments in universities. Such interaction is rare: often, the technical university is on the other end of town, and even where it isn't, the mental gap is large: students from these disciplines don't take each others' courses, unless they are forced to.

A laudable attempt to bridge this communication gap is Robert Pirsig's *Zen and the Art of Motorcycle Maintenance*. He shows how tackling repair problems that seem mundane, can be a highly creative, perhaps even spiritual activity. As he puts it, "Flight from and hatred of technology is self-defeating. The Buddha, the Godhead, resides quite as comfortably in the circuits of a digital computer or the gears of a cycle transmission as he does at the top of a mountain or in the petals of a flower. To think otherwise is to demean the Buddha... which is to demean oneself".

Bridging this gap has become far more important now that the world is changing very rapidly through advances in the field of information technology. Many new professions and industries have been created, including programming, web designing and systems administration. Others, such as mail and publishing, have been dominated, while other, like typesetting, even destroyed. Many big industries, such as music and telecom, are reeling under its impact. TV and cinema may be next.

Now that technology is receiving unprecedented media attention, so are its creators. Related, perhaps, to the relative newness of the Internet, there is now more glamour to be found here than in conventional branches of engineering. A student contemplating a choice between a career in marketing and computing can ask herself the same infamous question that Steve Jobs used to convince John Sculley to leave the giant Pepsi corporation for the then tiny Apple: "Do you want to spend the rest of your life selling sugared water, or do you want to change the world?".⁵ Indeed, there are many on the Internet who can lay claim to having significant part in changing the world: the members of the Internet Engineering Task Force, those in the open source movement, those who devised the software for mailing lists, chat, peer-to-peer file sharing, Internet Telephony...

Gilmore's Hypothesis

For a new technology to replace an older one is nothing new. Such innovation generates plenty of money for the industrialist, if the buyer can be persuaded to replace old products. However, on the Internet, in addition to an economic component, the role of the engineer has taken on an entirely new dimension – one which makes it vital for engineers to pay closer attention to what they can learn from the humanities departments. John Gilmore said, "The Internet treats censorship as a defect, and routes around it". This is a characteristic with political import. It was Arthur Koestler who said (I believe) that all it needs for the demise of authoritarianism is the free flow of information. Combine the two statements, and it would seem that the Internet and authoritarian regimes are incompatible. How does technology assume such political overtones?

Partly, what Gilmore said is a statement about the basic design of the Internet, which

had as one of its objectives, robustness. If a part of the network became defective, the rest could automatically reconfigure itself, essentially routing around the defective part. The technology underwent a veritable test by fire during the Gulf War. Iraqi defense communications, built on the same technology that powers the Internet, could not be taken out entirely, no matter how hard the powerful opposition tried.⁶

This characteristic of the Internet is also a consequence of the relative lack of sophistication in decision-making that electronics is capable of. The Internet is a highly automated communications medium and any process which cannot run autonomously by electronic machinery is expensive and doesn't work very well on it. Censorship is a sophisticated decision-making activity. It requires extensive human intervention. However, as computers become increasingly sophisticated their capabilities will grow and this could change.

What started out as sound engineering design has, with the growing importance of the Internet, become something far more: a serious threat to the functioning of authoritarian countries such as China. No less serious is the damage that the music industry perceives peer-to-peer networks are causing. The movie business worries that, as Internet bandwidth improves, it will be next. Yet, try as they will, such political and economic powers seem powerless in influencing the direction of technology development on the Internet.

Directing Technology Development on the Internet

What is indeed unique about the Internet as a technology is the manner in which it develops. Arguably the only significant governance the Internet enjoys is that of the Internet Engineering Task Force. These people manage a process that ensures that the Internet keeps acquiring new abilities at a furious pace that leaves policy-makers and the legal system far behind. The bureaucrats at international decision-making bodies, such as the UN, must wonder how it maintains this speed in a process that is remarkably inclusive, consensual and transparent.

The IETF doesn't take decisions in favour of one approach or the other: if even after thorough discussion, there is a difference of opinion on how a certain objective is to be achieved, all the variants can be tried out, without fear of doing any serious damage. With the characteristic modesty of an engineering body, the standards that the IETF encourages the Internet to follow are published as "Requests for Comment". If, after some experience with the variants, one stands out, a new RFC that points this out supersedes the earlier one, and the discussion moves on to other objectives.

Handed earth shaking power, engineers have come up with a process to channel it effectively. This is hardly unfamiliar territory for them: learning how to harness power is what they have practiced since the beginning. The difference this time is that decision-making relating to the development of technology is not taking place behind the closed doors of conference rooms. The reason why the Internet turned out differently is that engineers and others interested in the development of technology could communicate.

Imagine, for instance, how the pharmaceutical industry might be different if it were to use the Internet model for development. To start with, molecules would be open source: companies would not have to pussyfoot around the patents of their competitors and reinvent the wheel. They could instead focus on improving medication that was proven, and

therefore testing costs would go down. With raw materials available locally almost everywhere, production could be local too. There would be no marketing costs (ask Google). And finally, without IP costs, the price of medication would be only marginally higher than raw material costs, i.e. almost nothing, so many more lives would be saved.

However, the problem that pharmaceutical, and not Internet, companies faced was that their products could maim and kill people. Therefore a huge bureaucracy became involved in deciding what was researched, tested and approved for sale. Costs went up and the answer that the industry found was to bring in the concept of intellectual property. This made its products vastly more expensive and the process of designing and marketing them terribly inefficient.

Is the Internet model applicable in the rest of industry? It would be worthwhile to find out. The benefits to society of applying the Internet model for decision-making in technological development would be immense. In effect, this would be a much needed extension of democracy into a vital aspect of human existence.

The Education of Engineers

In light of the added responsibility that the Internet thrusts on the profession, a reexamination of the education imparted to engineers becomes vital. People with such power need to be taught ethics, and have a clear understanding of the legal aspects of their work. For instance, if the engineers who worked for Napster had a better appreciation of copyright law the company might well have survived its legal battles with the music industry. Engineers often have to make business plans these days, so financial skills are essential. Most important, however, are communication and teamwork skills – including how to participate in and chair meetings both on and off-line.

It is also a mistake to think that the education of an engineer is a one-time affair. According to Papert and Caperton, "Digital technology in the workplace requires a new definition of 'basic skills'. The transformation of work requires much more than a mastery of a fixed curriculum inherited from past centuries. Success in the slowly changing worlds of past centuries came from being able to do well what you were taught to do. Success in the rapidly changing world of the future depends on being able to do well what you were not taught to do".⁷ Engineers must, therefore, have ready access to their teachers and colleagues in the event that they need to learn something new.

A far more holistic approach to engineering education has become necessary. Engineering colleges focus almost exclusively on science and technology subjects, ignoring the other needs of their students. However, given the limited background and skill sets of faculty members at these colleges, one really cannot expect much more of them. It is time to bring the community of engineers back into the process of engineering education – as both lifelong students and teachers.

Distance learning technologies running on the Internet offer an excellent platform for engineers to participate in courses as teachers or students, either from home or the workplace. Chat rooms that offer quality audio-conferencing, text chat and shared whiteboards are now commonplace. Facilities such as this would also make it simpler for non-technical people to participate in the education of engineers. No longer can it be acceptable that

engineering education takes place in an environment divorced from industry. The PC is a potential software factory, so it is far easier to train people 'on the job'. Indeed, if students are required to participate in open source development projects at portals such as sourceforge.net, they will not only learn highly useful technological skills in the company of their seniors in the profession, but also imbibe better attitudes towards the ownership of ideas. The rapid pace of change in the IT environment also gives the young a relative advantage, making it harder for their teachers to behave in an authoritarian fashion.

The Internet has brought many changes for engineers. It has diminished their anonymity and isolation, increased their importance, taught them communication skills and forced another look at the manner in which they are educated. A necessary change in the role of the engineer in the information age is that she now also needs to become a teacher.

NOTES

1. <http://www.ee.bilkent.edu.tr/~eeweb/eee101/definition.html>
2. http://www.nobel.no/eng_com_will1.html
3. <http://www.research.att.com/~njas/doc/shannonbio.html>
4. Senge, Peter, Nelda Cambron-McCabe, Timothy Lucas, Bryan Smith, Janis Dutton and Art Kleiner *Schools that learn: A Fifth Discipline Fieldbook for Educators, Parents and Everyone Who Cares About Education* (Nicholas Brealey Publishing, 2000).
5. Sculley, John and John Byrne *Odyssey: Pepsi to Apple: A Journey of Adventure, Ideas, and the Future* (HarperCollins, 1989).
6. Levine, John and Carol Baroudi *The Internet for Dummies* (IDG Books, 1994).
7. Papert, Seymour and Gaston Caperton "Vision for Education: The Caperton-Papert Platform" (http://www.papert.org/articles/Vision_for_education.html).



