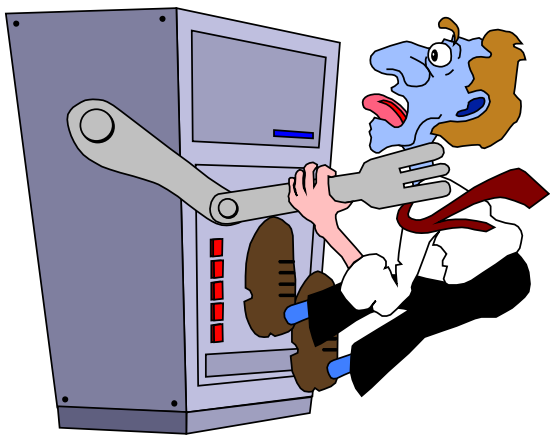


# 4

## The Computer Devolution



George Orwell once said that "to see what is in front of one's nose needs a great struggle". And so it is with computers and information technology. The difficulty is that technology has been pushed so far under our noses that we are unable to discern how much of it is beneficial and how much of it is detrimental to society and industry. Although decades will have elapsed before we can gain a clearer perspective on how computers and information technology affect society, their influence on industry and competitiveness is somewhat easier to assess.

As a starting point, it would be reasonable to suggest that technology only has benefits to industry while organisations possess technologies that are not available to, or possessed by, their competitors. Even then it is not always clear whether technology, in itself, provides a competitive advantage - in many instances it has proven to be a disadvantage. The key point is that technology is often only a tool for achieving some other objective. The problem is that technology tends to become an end in itself and those who use it often become addicted to its application rather than to achieving more important objectives.

The adage that *one computer can do the work of twenty ordinary men but no computer can do the work of one extraordinary man* is particularly relevant here. The adage encapsulates one of the fundamental roles of computers and technology in general - that is to eliminate manual-repetitive tasks so that humans can perform interesting knowledge-intensive and skill-intensive tasks more efficiently.

Since the mid-20th Century, however, the science-fiction aficionados have toyed with the idea that computers will ultimately become more intelligent and more influential than humans. Ironically, after half a century of supposed "revolution" in the semiconductor industry and the computer industry, and despite massive reductions in component size, massive increases in storage capacity and component reliability, the basic principles of computer architecture remained largely unchanged during the latter decades of the 20th Century. Within the first decade of the 21st Century, computers will still be little more than electronic machines, founded on the original Von Neumann principles, established decades earlier. In functionality, computers will still be little more than electronic slide-rules; electronic document-storage-and- retrieval cupboards; electronic typewriters; electronic drawing-boards; electronic pin-ball machines and electronic postal systems. Important as some of these functions may be, we might well ask whether or not there has

really been any revolution at all or have we just been naive enough to accept industry and academic hyperbole without question.

In the middle and late 1960s, man was able to use then-existing technology to create a device to go to the moon and to return to earth. Three decades later, despite an (unforeseen) increase of over a hundred-fold in computer processing and storage power, man achieved little more in that arena. The irony was that, viewed from the perspective of 1950s and 1960s science-fiction writers, there was a belief that computers and technology would almost certainly have led to intergalactic travel by the end of the 20th Century. The reality was that the biggest changes that computing and technology brought about, in half a century, were not really related to doing spectacularly new and exciting things at all but, rather, doing the same sorts of things we used to do before, only better and at less cost.

The most dramatic impacts that computers and technology had on society were, for the most part, both subtle and invisible to the majority of people because they often occurred under their very noses. The advancements in computer control, as they were applied to manufacturing (in the form of computer numerical control (CNC) machines, robots, surface-mount machines, flexible manufacturing systems (FMSs), etc.), enabled factories to produce very complex mechanical/electronic (i.e., "mechatronic") items at a very low cost and with an extremely high level of reliability. The consumer products that the developed world currently takes for granted (cars, sound and video equipment, washing machines, refrigerators, etc.), therefore, changed enormously over the course of half a century but these changes were often invisible. Most of these items still appeared much the same and still performed the same sorts of functions but they did so with a much higher level of reliability and they became available to a good many more people because their relative costs were reduced. For example, the cost of a refrigerator or television reduced, in relative terms, by a factor of ten over half a century. The relative cost of a car remained similar, but the equipment and safety levels, provided for that cost, improved dramatically - some features that would have been inconceivable in a 1950s Rolls Royce became commonplace in minimally-equipped vehicles of the 1990s.

In the developed world, and from a wealthy (*money is no object*) consumer's point of view, it would be reasonable to suggest that a half-century of technology brought about few changes. After all, houses in the 1950s were as lavish, if not more lavish, than those of the modern era;

expensive cars were very well equipped; expensive high-fidelity sound systems were only marginally worse than those of the modern era and the basic home appliances still performed much the same functions that they did half a century later. Banking and financial transactions in the 1950s were somewhat slower but still achieved much the same result. It was possible to travel the world in the 1950s, and generally with a higher degree of luxury than in the present day.

One could also go back considerably further to see the minimal impact that modern technology has had on the lives of wealthy people. For example, a member of the Roman gentry had most of the luxuries held as important today, including indoor plumbing, central heating and so on. With the exception of the combustion engine and electricity (i.e., cars and appliances), life in, say, Pompeii, for the wealthy, was little different to that at the end of the 20th Century.

The real differences that technological change brought about occurred from the perspective of the poorer members of society. Whereas a poor youth, in the third-world of the 1950s, was destined to spend a life on a subsistence farm, a modern day equivalent has a much greater potential (albeit still limited) to travel half way around the world and, say, undertake a PhD in Engineering or Science in the United States or Britain.

The tangible benefits that computers and technology brought about to industry were therefore in the reduced cost of transport, communications and consumer goods, to the extent that they became commonplace, even in many developing countries. One could go further and say that the only real revolution that computers and technology brought about to the world was in the cost reduction and availability of "tools" (i.e., economic weapons) that, perhaps for the first time in history, created a "more even" playing field for both developed and developing countries and even gave undeveloped countries some opportunity to get into the game of industrial competition.

On the other hand, it would be somewhat difficult to pin-point any form of "technical revolution" that has been brought about by modern-day computers. After all, computational aids have been around for thousands of years in the form of the abacus, mechanical calculators, cash-registers and slide rules; computer machine controls have been around since the Jacquard Loom of the 18th Century; word-processors are nothing more than the modern versions of typewriters and printing systems, implemented by

Remington in the 19th Century; electronic mail and the global communications networks (information "super-highways") are little more than a fast version of the postal system that has been in place for centuries; magnetic and optical storage media are just a modern version of paper and so on. However, since the 1970s, the computer industry has fed society on a steady diet of marketing hyperbole that have alluded to a form of technical brilliance that doesn't appear to be borne out in reality. There is no doubt that computer technology has changed rapidly over the past half-century. However, that change has been almost totally developmental in nature and it can well be argued that there have been no quantum leaps in knowledge or output from the computer industry - in other words, no technical revolution. Therefore, it needs to be emphasised that the discernible revolution is in the speed and extent to which computer technology has been adopted throughout the world.

A good part of the allure that computers have acquired over the past half-century comes from the glamorous euphemisms that computer scientists, and the computer industry, have applied to relatively mundane developments. In a sense, they have played on the human emotions, and the appeal of science-fiction predictions about computing, by introducing terms such as artificial intelligence (AI), expert systems, neural networks, fuzzy logic and so on. The illusion that has been created is that electronic machines (i.e., computers) can do more than humans and are therefore "intelligent". Interestingly, however, they have acquired a reverential awe that is not applied to other mechanical machines - for example, an electric egg-beater is not treated as intelligent because it can mix batter more effectively than a human can with a finger. The 18th Century Jacquard loom was never regarded as "intelligent" even though it was a mechanically programmable computer.

The reality is that, from a hardware point of view, computers display little, if any, more intelligence than they did half a century ago when they were best described as electronic machines. They can, on the other hand, do mundane tasks much, much faster and much more efficiently than a human, just like an egg-beater or a weaving loom. So, if one is prepared to accept that the human brain is solely a device that performs an enormous number of mundane tasks very rapidly, then the development of software which can do the same (on an electronic machine) also needs to be considered as some form of intelligence. However, given that research into the field of human intelligence is still somewhat rudimentary, it is better that we learn to view

computers with the same awe that is applied to electric egg-beaters, rather than with an awe that should be reserved for higher powers.

One of the problems that will impede any "revolutionary" change in computer technology, over the next decade, is the inertia that the existing industry has built up and its dependency on consistency and evolution (rather than revolution) in computer hardware and software. For the most part, the computer industry has been founded on selling minor changes in hardware and software as "revolutionary", just as the automotive industry and laundry-detergent industries sell their minor changes as "revolutionary". An examination of half a century's advertising, in the various forms of print media, reveals that the world responds well to revolutionary new products, provided that they are much the same as the old products but with a newly-discovered "secret ingredient" that acts as a panacea for all their problems. So, whether it is a laundry detergent with revolutionary "chlorophyll" added; a toothpaste with revolutionary "mono-fluoro-phosphate" added; an automobile with revolutionary "hydrodynamic" transmission or a computer system with a revolutionary "intelligent" operating system, the objective is to sell minor changes as major breakthroughs. However, in the case of computer technology in the 1980s and 1990s, the public's knowledge (and, for that matter many professional engineers' and scientists' knowledge) was so limited that people came to accept advertising hyperbole as fact and a "computer revolution" was born.

Although the impact of the computer industry jargon and hyperbole will erode as societies become more familiar with the application and limitations of their products, we are still left to ponder whether there will be any "revolutionary" changes over the coming decades. In reality, the computer industry suffers from the same problems as any other large conglomeration of companies associated with a particular type of product. The members of the computer industry have so much money invested in infrastructure and product development that they simply cannot afford to contemplate "revolutionary" change, any more than automotive and petrochemical companies can afford to contemplate revolutionary fuelling for vehicles, until forced to do so. With this in mind, we can assume no more than a steady development of existing computer and information technologies over the next decade and we therefore have an opportunity to evaluate the changes that these technologies have brought about, and will bring about, to industry. We can also consider how these changes impact upon undeveloped,

developing and developed countries and the way in which they compete at an industrial level. The key issues to be addressed include:

- Accessibility of information and data
- Change and competitive advantage
- The up-take of technology
- Change and productivity loss
- The necessity for constant training and skill upgrading
- The impact on product design and application.

Examining each of the above points in turn, we can begin with the assumption that knowledge is power and that, since knowledge is acquired from information, then information is, potentially, also a powerful entity in industry. The rapid escalation in the availability of information, as a result of computer technology and global computer networking, therefore has serious implications for those who generate new knowledge and information and for those that utilise it.

In an industrial sense, it is self-evident that a key objective of business is to acquire as much information as possible, at minimal cost, and to add value to that information by converting it into knowledge that can be used to generate products. Naturally, a secondary objective is to conceal that knowledge from competitors in order to retain a commercial advantage. This creates two questions that need to be answered. The first is whether computers and information technology have made it easier for organisations to acquire "knowledge" or whether they have just made it easier to acquire "data". The second is whether or not computers and information technology have made it more difficult to retain a competitive advantage.

In the case of information, more isn't always better, particularly if more information means that it is more difficult to find what one specifically needs. Within the office environment, computers were largely responsible for making more information available - longer reports and proposals with more numbers, more graphs and so on. The computers that were initially designed to bring about the "paperless" office ended up creating more paper than at any

previous time in history. The key question is whether or not computers have added more knowledge to society, and greater efficiency to the operation of a business, or whether they have just added more (redundant) information that people neither need nor use.

More also isn't better when more means that the checks and balances that normally occur with public information are ignored or by-passed. The global computer communications networks, that were established in the 1980s and 1990s, suffer from both these problems. In principle, global computer communication networks are little different to the postal system or the telephone system in the sense that they allow individuals to share and exchange data. The most significant difference is that computer networks enable people to *broadcast* data at a minute fraction of the cost associated with postal, telephone, radio or television-based communication. This theoretically enables (indeed encourages) people to *broadcast* information.

One of the great advantages of the traditional postal and telephone systems was that it was impractical for individuals to broadcast information because of the cost. This meant that information could only be transmitted through various media broadcast channels - newspapers, radio, television, books, journals, magazines, etc. These channels were responsible for performing filtering (editing) functions that theoretically precluded the dissemination of meaningless, or incorrect, information. Information that was deemed suitable for dissemination was then converted into a standard format (e.g., spelling and grammatical errors corrected) so that there was some consistency in presentation. Even then, it was apparent that the task of filtering information, and making it presentable, was beyond many of the channelling bodies that were often subjected to political and/or commercial biases. Nevertheless, given a reasonable array of media channels and ownerships, the information presented to society at least broadly reflected reality (if not always in precise detail).

An interesting feature of broadcasting is that when the number of channels exceeds some minimal threshold, the quality and accuracy of the output tend to deteriorate. Some 2000 years ago, the four evangelists, that were largely responsible for the New Testament in the Christian Bible, recounted in considerable detail, events that they had each witnessed decades earlier. The remarkable attribute of the text was the consistency with which the four had described historical events, despite the fact that the accounts had been written separately and, apparently, decades later. One of the reasons for

this consistency was that, 2000 years ago, writing (broadcasting) skills were a rarity and those that possessed them regarded them, and their accurate reproduction, at an almost sacred level. However, compare this with modern news accounts of an incident that may have occurred only minutes before broadcast - it is difficult to find two consistent reports of the same incident. The point here is that as information sources proliferate, the information tends to be cheapened in the process and the legacy is a loss of accuracy.

If one roughly compares the number of "broadcasters" that existed 2000 years ago (leaving aside street-side orators) with those that exist today, then one finds that society has moved from having, say, several thousand, to somewhere in the order of, say, several hundred thousand worldwide (including all newspaper, television, radio, magazine, journal, book publishers, etc.). This is not really a significant increase, given the enormous growth in population but, on the other hand, the penetration of each outlet is much greater with the more modern forms of broadcasting. Nevertheless, there has been a decline in standards - that is, in the quality of the information. One only has to go back a century, and compare media of the same form (e.g., newspapers), to see that, although there is more information available today (and available more rapidly), the accuracy is considerably more dubious. Consider then, the implications of moving from several hundred thousand broadcasters to (say) five billion broadcasters within the space of one or two decades, for that is the implication of the global computer-communications networks.

Modern computer and communications technologies empowered every individual with the ability to become a broadcaster. The problem is that once this occurred, many of the traditional mechanisms for filtering information, and converting it into a suitable presentation format, became redundant. While some argued that this represented an unprecedented level of democratic freedom, the reality was that an unrestricted ability to broadcast meant that the demarcation between fact and fiction was lost in the process. Information only has value when one can place a level of trust in that information. How then can one ascribe trust to the enormous amount of information that is broadcast on global communications networks? One of the problems with global communications networks is that the information all looks much the same, whether it emanates from one of the world's most respected universities or from some radical political group on a small tropical island. In the past, one could resolve such problems by ascribing confidence levels to information based on its source - for example, one gave greater

credence to information published in a refereed scientific journal than to the ravings of a street-side orator proclaiming that the end of the world was nigh. However, in the present day, the street-side orator has similar broadcasting privileges to those accorded to the world's most respected journals and universities.

The so-called "information super-highway" was, in many ways, another of the great myths adopted and promulgated by computer hardware and software industries because it served as a powerful marketing tool. The super-highway myth was founded upon two other partial myths - the first, that there would be much more information available to people than ever before, and the second that the information would be available much faster as a result of computer communications.

Changes in society, science, technology and population mean that there is always more information available to people. However, the "super-highway" added only a negligible amount to this information (i.e., information about the super-highway itself). The total amount of information therefore didn't change very much at all, only the format and accessibility of that information.

The idea that information was available faster than ever before, as a result of the "super-highway", was only partly accurate. The bulk of the delays associated with other forms of broadcasting (newspapers, magazines, journals, etc.) generally existed because of the time involved in verifying and filtering information. Given that, even half a century ago, a newspaper could be edited, compiled, printed and distributed within several hours, one could hardly suggest that reducing the distribution component alone is of major benefit to information consumers. Many scientific, engineering and professional journals take more than a year to publish information after it has been provided by authors. The long delay is not based upon technical limitations in printing or distribution but, rather, on the level of verification that occurs before publication. Global computer communications networks therefore only made significant time reductions through the elimination of basic filtering and editing functions provided by traditional channels. On the other hand, there were some smaller time savings in the time taken to distribute information. The problem was that these marginal reductions had to be counterbalanced against the increased time used in extracting meaningful information, from that embedded in a morass of text, broadcast by computer-based "street-side orators".

There are positive aspects to global communications networks and the ability to broadcast. The most significant is the establishment of a global community, largely independent of political boundaries. Again, this is not really a new phenomenon, but rather a more modern version of the ham-radio phenomenon that arose during the middle of the 20th Century. The major differences are in the extent of utilisation and the quality and quantity of the information that can be transferred. Whereas ham-radio was voice-only, the global communications networks offered the potential for voice, video, text, data and graphics interchange. Scientific, technical and business information became available, and could be transferred, through a community of users, from the wealthiest and most advanced countries to the poorest and least advanced countries.

Whether or not it can be argued that computer communications technology has changed society is highly debatable. Perhaps, it is more a case of technology becoming available at an appropriate time, and society responding favourably to that technology. After all, the ham-radio phenomenon arrived during a period of Cold War between the (then) super-powers; an emerging threat of Communism in Europe and Asia; the advent of Communism in Cuba; a heightened paranoia between countries in general; apartheid in South Africa and segregation in the Southern States of America. Little wonder then that it did not become a basis for a global community. On the other hand, global computer communications networks emerged after a thawing of East-West relations, signs of peace in the Middle-East, the abolition of apartheid in South Africa and segregation in the Southern United States and the diminution of Cuba as an international entity. So, it may well be argued that the global communications networks did not represent a "world-changing" technical revolution at all but, more accurately, an appropriate technology for the times in which they emerged.

There is also, however, a case for arguing that technology ultimately brings about political reform and the avoidance of totalitarian government. In particular, it could be argued that Communism in Eastern Europe would have remained in force provided that the governments there could have controlled the flow of information to their citizens. As it eventuated, communications technology made it extremely difficult for the old regimes to cover up the extent of the economic and political damage that had been brought about through Communism and, worse still, that the relative economic position of these countries was far worse than that of their former capitalist enemies. In this case, the proliferation of information was not a direct result of computer

technology but, rather, an indirect one. The demise of Communism began in the mid-1980s, at a time when computer technology had not penetrated deeply into Eastern European countries. Information flow therefore occurred through more traditional broadcasting techniques, such as radio and television. However, it could be argued that these items would never have proliferated to the extent that they had, and for the low costs to which they had descended, if it were not for the advent of computer-based production techniques.

If one is prepared to accept that, for whatever reason, political changes have occurred and that computer networks are a now popular mechanism for the international exchange of science and technology, within an international community, then one also has to accept that the traditional political and corporate boundaries, that provided a defence against competition, are no longer secure. Again, it isn't simply a question of technology breaking down defences, because the same information could be sent, equally well, in an envelope carried by ship and mule-train. It is a question of the globalisation of engineering and science, as a result of diminishing political boundaries, and an end to the notion that such knowledge can exclusively reside within one country.

From an industrial perspective, therefore, companies have no more to fear from information super-highways than they do from the postal system. The issue that should concern them is that knowledge, which once gave the developed world a competitive advantage for a long period, is spreading to the developing and undeveloped countries at a much faster rate. If one considers the world's automotive industries, some interesting examples emerge. Consider that it had taken leading European and American car manufacturers well over half a century to achieve the level of quality and technology in the cars that they produced in the mid-1980s. If one takes the 1964 Olympics in Tokyo as the beginning of the renaissance for the Japanese automotive industry, then by the mid-1980s, their corporations had equalled, and often bettered, the competition (i.e., in under two decades). Similarly, if one considers the birth of the South Korean car industry as being in the early 1980s, then the transition to an industry capable of competing with (and bettering) leading European, Japanese and American rivals occurred in less than one decade. There has clearly been an exponential decay in the amount of time required to create world-competitive manufacturing plants in developing countries.

Most companies do not publish, what they perceive to be, commercially-sensitive technical information because they believe that the information may have immense value. However, it is not the information that necessarily has value but, rather, the ability of the company to use the information to create viable products. And, more importantly, to continually change and develop new products in response to changing demands.

The relative commercial value of technical information is, therefore, generally limited by the ability of competitor companies to commercialise that information. For example, the designs for a new space shuttle are of little value to a backyard company that assembles lawn-mowers in India. Even when a similar competitor company has the opportunity to steal technical ideas, much of the incentive is lost because most organisations have their own research, development and commercialisation plans that need to be implemented over several years. Products don't just emerge overnight - they need to be supported with technical skills, manufacturing capacity and infrastructure. The glamorous stories of industrial espionage that were once founded on "the secret formula" are rapidly fading as companies realise that ideas and formulae are "*dime a dozen*" commodities that are meaningless unless those using them have a strategy and capacity for implementation and commercialisation. The other hard reality is that the era of the "earth-shattering breakthrough" has largely ended.

Most new products come about through a lengthy developmental process. Initial research (referred to as basic or pure research) is normally undertaken by universities, government and military research agencies and is targeted towards expanding existing knowledge. Even at this level, work needs to be systematic and, at least, based on other research, so that it has an evolutionary (rather than revolutionary) progression. The outcomes of this research are often little more than ideas that have had testing in a rarefied environment, divorced from many industrial realities. The principal users of such ideas are large corporations (and government defence industries) that have their own research and development departments and laboratories - these tend to be the organisations that can advance embryonic ideas to the stage where they can be implemented. The secondary users tend to be small, high-technology companies that endeavour to gain competitive advantage through a rapid commercialisation of new knowledge. In both cases however, the emphasis is still on developmental progression rather than revolution. The outcomes of the developmental work need to be commercialised. In the case of physical products, this stage often contains more of the ubiquitous

"secret formula" than any other because it involves design for manufacture, tooling, marketing strategies and so on. It is this stage that often defines whether or not an idea can be converted into a successful (i.e., competitive) product.

The evolutionary process, associated with commercialisation of new ideas, highlights the fact that it is not the ideas which have any latent value but, rather, the organisation and the people that can convert them into competitive products. Hence, when we examine the emergence of countries such as post-war Germany, Japan, South Korea or Taiwan as economic giants, within ever decreasing time-frames, we should note that these countries are not becoming successful because they are "stealing" product-related ideas in the technology field, but because they are becoming better and faster at establishing companies with "doing" knowledge.

Again, we have a situation where it is not the global communication networks or the so-called "computer revolution" that are directly responsible for the rapid growth of competitor companies in the developing world. These technologies have merely been useful tools that have emerged at an opportune time. The real problem has been that while companies in many Western countries have been jealously guarding their "secret formulae" with costly and often indefensible patents, they have failed to protect their true assets - the corporate structures and production techniques that have given them the ability to develop competitive products. In reality, there is no steady flow of secret formulae to the developing world, as a result of modern technology, and the fruits of pure research have generally been available, free of charge, to anyone who cares to use them. The developing world hasn't been "stealing" product ideas as much as they have been studying the "doing" processes and adopting all the best principles of those processes in order to create successful new companies.

A good example of what actually occurs in technology transfer is where large companies (donor companies) establish production plants in developing countries in order to reduce labour costs. While the donor companies are busy guarding the "secret formula" of their state-of-the-art products (e.g., semiconductors or software), the developing countries are studying their production techniques, costing and management structures. Unencumbered by the need to produce leading-edge products, the developing countries establish clone companies producing not-quite-state-of-the-art products but at a very low cost. Since the success of most high-volume

companies is founded on the production of low-cost, reliable, mediocre-technology products, the clone companies very rapidly rise to the same level as the original donor companies. Within a short time-frame, they can establish similar research and development facilities and ramp up to a level where they too produce state-of-the-art products. The new companies have a much leaner management structure (because they tend to adopt only the best attributes of the donor company) and often lower labour costs (although these are less of a consideration in automated environments).

One therefore has to be very careful in ascribing blame, responsibility or credit to technologically-based tools, such as computers and networks, simply because they are marketed as being intelligent devices. The industrial changes that have occurred over the past half century are as much about political and societal changes as they are about technological change.

On the other hand, technological tools can assist in the process of industrial development if they are correctly applied. The problem is that the rapid pace of technological development, particularly in computing, makes it difficult to know how to apply tools to best advantage. The natural learning process is to make mistakes and to develop new skills in the process. Even better, however, if someone else can make the mistakes and one can just adopt the new skills as one's own (after all, *originality*, it is said, is *the art of concealing one's sources*). In developed countries, where labour costs are significantly higher than they are in developing and undeveloped countries, competitive advantage generally comes from innovation. In other words, if product costs are higher, then products must either be more technically or aesthetically advanced or of better quality (all of which generally amount to the same thing). This leaves most developed countries with the responsibility of making technical mistakes and learning from them. On the other hand, undeveloped and developing countries gain competitive advantage from lower product costs and so have more lee-way in adopting technology - these countries therefore have the opportunity of learning from others' mistakes at little or no expense.

A good and simple example of where developed countries have had to learn from costly mistakes (which ultimately benefited others) occurred with the introduction of computer-based word-processing in the mid 1980s. Many companies, in the developed world, adopted the technology in its infancy, only to find that there was little (if any) compatibility between packages and printers; that the packages and printers were constantly changing from one

form to another and so on. Some companies adopted costly mainframe and workstation based word-processors and publishing systems, while others chose crude personal computer (PC) versions that were heavily constrained by hardware, networking and printer quality and cost. Given the enormous amounts of time and money wasted on implementing such systems and training (and retraining) staff, and the problems with incompatibility, it is difficult to know whether many organisations derived any benefits at all from the early technology. By the early 1990s, both the hardware and the software had stabilised and standardised (albeit to a defacto level) and word-processing and desktop publishing became a worthwhile investment. Many developing countries, which often ran several years behind the developed world in the application of technology, were able to move from no word-processing to stabilised packages and hardware without the trauma and headaches that had occurred elsewhere. Although this is a relatively trivial example, it is typical of the phenomena that occur in more significant areas of computer and production technology.

The above word-processing example is interesting because it also highlights several other points about the so-called "computer revolution". The first issue is that leadership in the adoption of technology always tends to be costly and, hence, many companies are often engaged in a race to be second, so that they can learn from others' mistakes. The second issue is the loss of productivity that initially accompanies the introduction of new technology, particularly computer-based technology, into an organisation. The third issue is related to technology providers that generate change for the sake of change (or, more appropriately, change for the sake of maintaining cash-flow). The issue is then whether it is really necessary to always adopt new technologies.

In the developed world, the ability to compete on cost is severely hampered by the cost of labour, when manual-repetitive processes are involved in the generation of products and services. Of course, cost competitiveness in developed countries is also hampered by the excessive overheads associated with management, marketing and so on but there is little potential for these items to be removed through technology alone. The only real competitive advantages that products, in the developed world, can have are therefore derived from quality or design innovation or through automation of manual-repetitive tasks. All these advantages tend to be derived through technology.

Many manual-repetitive tasks can be automated without state-of-the-art technology (through dedicated production equipment) provided that production volumes are sufficiently large. In many ways, therefore, international competitiveness is best suited to larger organisations that can have a reasonable blend of mediocre-technology and high production volume. Small and medium-sized companies, on the other hand, do not have the production volumes needed to justify dedicated automation and so need to invest in technically-advanced flexible automation (which has a high cost and risk) or to tailor their products for niche markets (which requires the provision of state-of-the-art products or high quality levels). These smaller organisations have a much more difficult task ahead of them in terms of remaining internationally competitive.

Many organisations, in the developed world, therefore have no option but to lead in the technology race if they are to have a competitive advantage in an industrial sense. The only consideration is then in terms of the position that individual organisations hold, relative to competitors in the same country. The introduction of new technology always has incalculable initial costs associated with learning curves, poor product performance and change. However, in the race to be second, one also has to accept that there will be losers who will come first in introducing new technology and will bear the brunt of the mistake-making learning curve.

The learning curve associated with the introduction of new technology is not the same for all companies, even when the companies and the technologies are very similar. Those organisations that are first to introduce new technologies not only have to train their own staff but also have to contend with a shortage of external support in the training process. This is particularly serious for organisations introducing technologies that need to be mastered within a wide cross-section of an organisation (e.g., word-processors and spreadsheets, computer aided design (CAD), CNC machining and robotics) because the cost of training can be very significant. As technologies mature, the training process changes considerably. Firstly, there are more trainers available in universities, colleges, high-schools, etc. and at a more reasonable cost. Secondly, the number of pre-trained people in the marketplace increases and companies can hire such people for dual roles - composed of a specific job function and training of other staff. Thirdly, the role of the technology itself becomes much clearer and directions and trends are established.

In many instances, even when low-cost training is available, the introduction of new technologies into an organisation inevitably causes initial losses in productivity. Often, the problem is that organisations believe that technology is simply a new way of carrying out old tasks. The reality is that the introduction of a new technology generally requires a complete reorganisation of the way in which a department or company needs to function. The simple word-processing example is a good illustration. The replacement of typewriters, with word-processors, introduced the need for organisational changes that were often not addressed until nearly a decade after the introduction of the technology. Some companies used word-processors to generate text in files and then, rather than systematically archiving and backing up the files, stored only the printed outputs. Other organisations archived only the computer files and found that, after several changes in word-processor technology, the original documents and formats were very difficult to retrieve because the superseded word-processors had been discarded. In companies that originally used mainframe or workstation based word-processors, the transition to personal computers (without networking) often resulted in files that were not stored on a central reference database and multiple conflicting versions of documents emerged.

Word-processing is only one trivial element of the range of technologies that have been introduced into industry and, yet, it highlights the considerable productivity losses that can occur because of the failure to recognise the organisational changes that need to follow. A much larger example was in the widespread introduction of computer-aided design (CAD) in the 1980s. Initially, most companies treated CAD as a computer-based drawing-board system - in other words, a word-processor for pictures. Those organisations gained very little from the introduction of the technology, other than neater drawings and a reduction in the need to start drawings "from square-one". However, the purpose of CAD was not just to create electronic pictures but to create models that could then be more readily analysed and converted into an end-product. In aeronautical, civil or mechanical engineering, this could involve analysing stresses and aerodynamic properties. In manufacturing, the CAD process involved the automatic generation of machining programs for computer-controlled machine tools (i.e., computer aided manufacturing or CAM). In the former (manual) approach the task of designing technical products was divided into a drafting phase and an engineering design phase. In the CAD approach, both elements were unified within a single piece of software. The problem, therefore, was that, in introducing the new technology, the existing staff (draftsmen and

engineers) were inappropriate in their previous form. In some cases, an altogether different breed of technocratic staff was required.

The CAD example is particularly important because it highlights the fact that training alone may not resolve the problems associated with the introduction of technology. In other words, a technical person cannot be "trained" to become a "professional" through a short course of education, because the background requirements are altogether different. Similarly, a professional may not be capable of becoming a technical person, because dexterity requirements are altogether different. So, the introduction of a technology may have far more wide-reaching implications to an organisation than are initially apparent. In the past, of course, one could readily identify that if a manual production process was to be replaced with an automated transfer line then there would need to be a considerable reorganisation or retrenchment of staff. The difference with computer-based technologies is that the introduction is far more subtle but the consequences are far more dramatic and occur at a much higher level within the organisation. Many companies find it too difficult to deal with such problems and hope that time will naturally resolve them. In the case of CAD, for example, time did tend to resolve the problem because university and college courses introduced specific subjects, related to the technology, and created an appropriate breed of technocrat to fulfil the roles. The previously inappropriate staff gradually disappeared through natural attrition.

The problem, for developed countries, is that these largely-hidden technology introduction costs often aren't shared by developing countries who have the benefit of a several-year time-lag in which they can resolve problems before they become serious. In other words, developing countries have the benefit of hindsight derived from developed countries, often at enormous cost (to the developed countries).

It would be easy to dismiss the turmoil, cost and productivity loss caused by the introduction of new technologies (particularly computer-based technologies) if the technologies were a one-off phenomenon. However, computer industries are faced with their own problems, chiefly that products tend to be extremely reliable, long-lasting or, in the case of software, perpetual. In order to maintain cash-flow, computer organisations have to continually introduce new products under the pretence that they are "revolutionary" and/or that they satisfy some overwhelming customer demand. The result is a continuous stream of hardware and software

upgrades that make marginal improvements in functionality at the cost of considerable disruption, retraining and productivity loss. It would be reasonable to suggest then, that the most overwhelming demand for change tends to come from the need for hardware and software companies to maintain cash flow and competitive advantage, rather than from the customers themselves.

The classic example of the disruption caused by continuous software upgrades is well illustrated by the changes introduced to basic packages, such as word-processors. From a historical perspective, we know that typed text in the office environment has been in common usage since Remington introduced the typewriter in the middle of the 19th Century. The objective was to create a simple device that would produce neat readable text for business purposes. So successful was their product that it remained largely unassailed (and largely unchanged, with the exception of correctable type) until the mid-1980s, when word-processors became commonplace. The lifespan of a high-quality office typewriter was in the order of ten to fifteen years and, because all typewriters were much the same, training was a non-issue because it was well covered in high-school education. However, from the mid-1980s through to the early 1990s, organisations were besieged by change after change after change. By the mid-1990s, the lifespan of the typewriter's replacement (i.e., the word-processor hardware and software) had been reduced to a two-year average, with variations between different word-processors, and incompatibilities between different versions and document-storage formats, causing both disruption and chaos in the office environment.

The pace of technological change has also made the traditional corporate pyramid difficult to maintain in a workable form. Generalists (at the apex) largely need to lead, based upon advice from specialists below - in other words, lead from the rear. Perhaps, in regard to small-scale items, such as word-processors, the selection of inappropriate items is unlikely to send a large company to penury. However, the inappropriate selection of large-scale technology, such as management information systems or manufacturing management systems, could well have a dramatic impact upon the performance of an organisation.

Technological changes also influence the way in which people operate and, as most humans seek the path of least resistance to achieving their personal objectives, the overall improvements that technology can bring are often compromised (or totally negated) by human factors. Referring again to

the word-processor example, many would argue that the ability of word-processors to provide cut and paste functions simplified the document preparation process and thereby led to dramatic efficiency gains. However, leaving aside the issues of non-compatibility between versions and of training and retraining, the efficiency gains provided by word-processors were not as far-reaching as one might expect. In changing office technology, software manufacturers also changed the way in which humans functioned. In the days prior to self-correcting typewriters, a good deal of thought had to go into each typewritten page because corrections were difficult and tedious. A person would have their thoughts clear in their own minds (or on hand-written notes) before committing them to type. Accuracy was also a necessity for typists because correction of mistakes was very difficult. In the word-processor (i.e., paperless office) era, the objective was to put every thought into a document file and then just re-arrange it to make it look respectable. The former approach was disciplined and the latter approach was undisciplined. The former approach was a rigorous (and tedious) method of preparing documents and the latter was a lax (and simple) way of producing a lot of text that, superficially, looked attractive. However, the differences showed quite clearly when one compared text, prepared in the 1940s, with that prepared in the 1990s. The former approach created well-structured sentences and documents and the latter approach tended to create quantity rather than quality.

The word-processing example again highlights the problems associated with computer technology. There is no latent attribute of the technology (e.g., word-processors) that should cause a decline in the quality of written text. In theory, the quality of written text should improve because the word-processor enables users to correct errors with minimum repetition. The problem is clearly not the word-processors at all but, rather, the humans that use them and their natural tendency to seek the path of least resistance. Hence, if the objective is to create an article, report or thesis (wherein it is assumed that the reader will only seek to find a lot of neatly arranged words), then word-processors allow them to meet their objectives with a minimum amount of work. If, on the other hand, the objective is to produce a well-structured and well-written document, then the word-processor will only provide marginal productivity improvements over the older (typewritten) approach. However, the illusion that word-processors have created in the mind of the modern reader, because of their ability to produce book-quality text, is that the content and substance matches the print quality, when in most cases it clearly does not. Here again, word-processing provides another

example of where the reality of the "computer revolution" is far removed from the marketing illusion.

The ability of computer-based systems to efficiently generate vast quantities of neatly-arranged text, data and graphics also leads one to wonder about the resulting devaluation of information. The more that people are exposed to automatically-generated text and data, the less they are inclined to read it - and so, the message gets lost. Mark Twain once encapsulated the problem when he said that he would have to send a long note because he didn't have time to write a shorter one. In a sense, computer technology has often given us the ability to write long notes without having to think about the message that could be contained within shorter ones.

Word-processing tends to highlight good examples of the myths of the computer revolution because it is relatively easy to understand the implications and human factors, pertaining to its exploitation, once the technology is dissected. However, it is far more difficult to dissect some of the other more-complicated computer technologies that have an impact upon industry.

Major purchasing decisions in any organisation are always enshrouded by a political cloud, created by those individuals that make the decisions, within the corporate pyramid. It is extremely rare to find organisations where individuals admit that they ever made *the wrong decision* about the technologies that they introduced, despite the increasing likelihood of incorrect decisions being made in a climate of rapid technological change. As has already been noted (in the case of word-processing), it is difficult enough to ascertain the value of a computer-based technology even when the impact is clear and when there are no attempts to disguise poor decision-making. Consider then, the difficulty of ascertaining the value of a complex and costly piece of hardware and software within an organisation, particularly when the process is cluttered with political factors associated with the corporate pyramid.

The purchase of any major piece of infrastructure or equipment always involves a degree of risk, whether it is a building, a production facility or a major computer installation. The problem is that, as the items become more technically complex, the risk of having an inappropriate course of action becomes more likely. In terms of major computer hardware and software installations, the decision and performance criteria are often so complex and

broad that the probability of making an inappropriate selection may be greater than the probability of making an appropriate selection. A political cloud therefore descends over such decisions when the decision-makers begin to rationalise a process that may have led to an inappropriate decision.

Consider, for example, the selection of a large-scale management information system (MIS), financial system or manufacturing software system. All such systems function in three phases - data entry, data processing and data output. The selection of a suitable system therefore depends upon a deep-level "doing" knowledge of all three phases of the process but this sort of knowledge is rarely possessed by an individual. Data entry is normally performed by partially skilled people that have little interest in, or knowledge of, the data processing and output phases. The data processing phase is the core function and it is normally professionals (i.e., accountants, systems analysts, production engineers, etc.) that are concerned with this phase. Data output is normally of concern to people who have no interest in the data entry or processing functions - typically sales and marketing staff, shop-floor personnel, etc. However, systems tend to be chosen by those most concerned with the data processing phase of the process because they are typically professional staff, generally with some computing background. The result is that the input and output phases are often neglected.

In large computer systems, a failure to consider the input and output phases, and the associated staff skills and interests, is potentially fatal. Personnel who find it difficult to enter data tend to either avoid the process; make more mistakes in entry; delay data entry (leading to processing of invalid data) or just enter meaningless numbers, as is often the case with large-scale systems that require users to enter times associated with the carrying out of duties. Those who find it difficult to access data tend to avoid the facility altogether. Therefore, the problem is that once a decision to purchase a particular system has been made, the political cloud, that descends over the process, tends to prevent any rational assessment of the effectiveness of the decision and the system that is in place. In some large installations, those responsible for the decision can rationalise mistakes by pointing to the fact that the system won't be fully operational until all the data is entered (which may take a several years) and then its lack of effectiveness can be attributed to the fact that the software is out of date and should be upgraded. In other cases, mistakes are not found until the next electronic data processing (EDP) manager is appointed and wants to make a mark on the company by

criticising the decisions of the previous manager and by installing a new system (whose effectiveness won't be apparent for several more years). There are also some cases, where the "system" becomes so all-consuming, that people are more concerned with its operation than they are with the operation of the core activities of the organisation itself.

In any event, the measurable benefits of any large-scale computer-based system are often extremely difficult, if not impossible, to ascertain. Sometimes, when benefits do occur, it is not because of the technology, but because an organisational unit becomes more cognisant of rigorous procedures that need to be introduced in conjunction with the technology itself. In other cases, when productivity appears to drop, it may also be because of the organisation and its procedures rather than the technology. In both cases, however, one has an environment where it is difficult to correlate large-scale systems with revolutionary change.

The most obvious large-scale computer systems that were available to the general public (in the 20th Century) appeared through the banking system, where it was claimed that computers "revolutionised" banking. But, did they really? A given bank could provide far greater services, with far fewer staff and potentially with far greater accuracy - but then, so could all the other competitor banks. Therefore, the relative position of a given bank changed little as a result of the technology. Similarly, businesses claimed that banking advances reduced their overheads - but they also reduced the overheads of all their competitors. And, they also increased expectations from all the other businesses and customers. From a consumer's point of view, there was an apparent globalisation of banking that made it far easier to access facilities at an international level and with unrestricted operating hours. However, it again became apparent that humans changed their habits in response to the technology. Whereas, half a century earlier, consumers would withdraw sufficient cash funds, to ensure they could survive until their next banking transaction, modern consumers assumed unlimited access and planned differently, often withdrawing less funds than they needed, on the assumption that they could get more later. Again, the technology was reduced to a matter of speed and convenience, rather than revolution.

The changes that computers made to banking will have less impact than the long-term changes that computers and communications technologies will make to manufacturing industries around the world. Leaving aside computer-based automation, computer networking, in itself, provides a

convenient mechanism for the globalisation of manufacturing industries because engineers, designers, production managers, sales and marketing staff can all work together as though they were in the same office. Although this sort of capability has long been available to large corporations, through private data networks, the globalisation of computer communication has provided a fast low-cost mechanism for groups to work together and to exchange a broad range of information. This has significant implications for manufacturing industries because it means that, theoretically, a company can be spread over several countries. High-value-added functions, such as product design, can occur in the home-base company while production can occur where costs are lower, or in target markets, so that transportation costs are reduced. Product design can also be spread through several countries, depending on the available professional expertise and its costs.

As an example of global manufacturing, consider a company that wishes to produce machined plumbing fittings. The company could set up a base on a remote tropical island, where taxation rates are favourable; receive country-specific technical, sales and marketing information from Europe and North America; carry out product design on the tropical island, using computer aided modelling; transfer computer models to specialist CNC machine programmers in a developing country, and then transfer the machining programs to the target countries, where the products can be machined. Funds can be transferred through international computer-based banking systems. The net result is that companies, theoretically, can minimise tax; minimise engineering and technical costs; minimise production and transportation costs while still maintaining the ability to quickly respond to local markets. Companies could then balance the various trade-offs of labour cost, transportation, etc. between countries. Of course, the real-world is not as easy to manipulate as this example suggests but, nevertheless, the trend towards globalised manufacturing commenced in the early 1980s, largely through multinational automotive manufacture. Some software companies also began operating as "international manufacturing" companies in the 1980s. In fact, in the two decades, from the 1970s to the 1990s, there was a tripling of the number of companies involved in global manufacturing.

The globalisation of manufacturing didn't really come about solely as a result of any computer revolution. The revolution was more in terms of the way in which humans began to perceive the world as a result of evolutionary advances in such technologies. For centuries, humans considered that the only way to acquire wealth and power was to invade other countries and to

take over other people's land and wealth. The lessons learnt from Eastern Europe in the 20th Century (and most of the other, earlier empire-building attempts) were that, in taking over other people's land and wealth, one also had to take over the other people. Common sense would lead one to the conclusion that if a country had difficulties in its own right, then these were not likely to disappear when invaded by another country. Hence, the empire builders discovered that invasion and colonisation led to immeasurable bureaucratic and social problems rather than merely land, wealth and power. Far better then, if humans could acquire wealth, through an exploitation of competitive advantage, and then purchase lands by peaceful means. The result was a form of economic warfare, which was far more civilised and effective than military conflict. For example, post-war Japan managed to acquire more real-estate in Hawaii and Northern Australia, through legitimate purchases, than it ever did through military force.

Global manufacturing became a relatively friendly form of economic warfare that had long-term benefits for both the exploiter and the exploitee - however, it also had short-term penalties for the exploitee nation, including pollution, poor working conditions, etc. Overall, the exploiters gained from low labour costs and/or poor working conditions but the exploitees also gained by acquiring a mechanism for their own form of industrialisation and wealth creation. In the final analysis, it may be that the penalties that the developing nations paid as a result of global manufacturing were part of the evolutionary chain and, perhaps, as unavoidable as the penalties that the pre-war-developed nations paid for their industrial revolution.

The advances in computer and communications technology have provided an ideal tool for economic warfare through globalised manufacturing. They have also provided an accelerated platform for the "exploitees" to use so that they can become exploiters. Referring back to the earlier example of global manufacture of plumbing fittings, one can see how machine programmers in a developing country could quickly rise to the level where they become a host company, that does its own design work, and contracts out lower-level work to other countries.

If nothing else then, computer technologies have provided a tool that costs relatively little and can be used to accelerate a society from flint-axes to software development in a matter of decades rather than millennia.

However, all the above examples also tend to highlight one of the fundamental reasons that computer technologies can rarely be revolutionary in themselves - that is, because those professionals, that create computer technologies, are also faced with the problem of developing products for which they cannot begin to understand the potential usage patterns. In other words, computer products are often "open-ended" in terms of their potential application because they are general-purpose tools. No-one can accurately predict how the tools will be used once they are accepted.

A company, manufacturing hammers, may reasonably assume that their product will be used for pounding on nails, but a user may see a hammer as a useful device for blocking the wheel of his/her car to prevent it from rolling down a driveway. In the case of hammers, the manufacturer can readily ascertain, that if most consumers use them for wheel blocking, then perhaps a different design of hammer should be contemplated. The computer industry has analogous problems but its tools are far more complicated and the consumers often don't understand why they can't use them for a given purpose. For example, a software company may develop a word-processor, with spelling and grammar correction, and, as a result, society decides that (given such technology) these traits should not be taught as rigorously in schools. The end result is that users are faced with a software-based grammar or spell checking system that makes suggestions that the user cannot understand - the software company therefore needs to revise its ideas in response. Hence, from a commercial perspective, the computer industry needs to focus on evolution rather than revolution in order to keep its customers trailing along.

Following on from all these discussions, one might be tempted to conclude that computers and their related technologies have not been responsible for any revolutions at all, but this is not the case. Computers are actually bringing about revolutionary changes to the way in which the world views engineering and science, both of which were largely founded upon mathematics. Until the advent of modern computing, mathematics was viewed as the fundamental tool for modelling the physical world and as a basis for controlling those aspects of it that could be controlled. Although some humans appreciate mathematics as a science in its own right, they don't tend to think mathematically when confronted with a problem. For example, if a human is confronted with a dexterity problem, such as the need to stop a rotating shaft (driven by an electric motor, say) most humans would:

- Visually examine the shaft and motor to ascertain its size and to determine whether it was possible to stop the shaft
- If it appeared possible to manually stop the shaft, then a hand would be placed around the shaft and an estimated level of pressure applied to stop the rotation
- If the originally-estimated force was inadequate, then a second estimate would be made based upon the feedback from the shaft
- If it appeared that the force estimates were both incorrect, or that the shaft could not be stopped, then the grip would be released to prevent heat build-up from friction.

Humans would not base their assessments of a manual dexterity problem on mathematical analysis of the motor and shaft but, rather, on a series of estimates which were, in turn, based upon previous experience and sensory feedback (vision, torque, slip between the hand and shaft, etc.). It may also be that a human's initial encounter with such a system would lead to a completely incorrect analysis of the problem (e.g., a motor may generate considerably more torque than its size might suggest). However, humans would eventually learn to characterise the behaviour of motors by observation and would refine their techniques. This may ultimately occur by, say, inspecting the specification plate for the motor and mentally correlating the feedback from the hand to specific numerical power/torque outputs.

It is considerably more difficult to train a computer control system to handle manual or mental dexterity tasks, such as in the previous example. The rotational velocity of the motor would need to be measured and fed back to the computer system and then a braking force calculated (computed) via some mathematical model of the system. The braking force would then need to be applied and the velocity measured again to see if the force was having the desired effect. The problem is that a simple mathematical model would probably be inadequate to accurately describe the phenomenon and so, either an error margin would need to be included or the effect of the force (i.e., new rotational velocity) measured after the force was applied. A different motor and shaft arrangement might necessitate the development of a different mathematical model.

In engineering and science, mathematical models are rarely an ideal way of describing the behaviour of physical systems - however, prior to the advent of modern computing they were one of few options.

Needless to say, mathematics always gives the correct solution, provided that the model and human assumptions are correct, but it doesn't always give the appropriate solution because accurate models are often extremely difficult to create and analyse. Even simple physical systems can require complex mathematical analyses in order to attain an accurate picture of the phenomena involved. In many cases, the physical systems are multidimensional in nature. This means that, in varying one input, a range of changes can occur within various parts of the system. Conversely, it may be necessary to vary many different inputs in order to change one output of the system a particular way. Often, the relationship between the inputs and outputs (of a system) has traits that can only be described by complex mathematical equations.

In all these instances, and particularly in engineering problems, there is a growing belief that mathematics, in isolation, is no longer an appropriate tool for solving many physical problems. These limitations were observed by Albert Einstein who said that:

*"So far as the laws of mathematics refer to reality, they are not certain. And, so far as they are certain, they do not refer to reality."*

Similarly, Lotfi Zadah, the father of fuzzy-logic-based computing, noted that:

*"As complexity rises, precise statements lose meaning and meaningful statements lose precision."*

Therefore, as a mechanism that engineers and scientists can use for solving the problems of physics and chemistry, computers have caused a form of revolution. However, this revolution has yet to be fully exploited because it requires a considerable change in engineering and scientific thought processes.

Computer technology has already provided a number of tools that are increasingly replacing mathematical modelling as a means for controlling real-world systems. Instead of exploring enormously-complex mathematical relationships between inputs and outputs, humans are now treating large

problems as many infinitesimally-small problems and computers are used to perform simple calculations on each part and then to combine the partial solutions into a total solution. In other words, rather than using complex mathematics to solve one large problem, computers and simple mathematics can be used to solve many smaller (simpler) problems that lead to a solution of the larger problem. This has brought about considerable changes to the way in which many complex systems and phenomena can be modelled and controlled.

The dramatic increases in computational processing power have also led to the replacement of traditional mathematical methods with more human-oriented techniques for doing things. In other words, rather than trying to mathematically model systems, computers can now be trained to take a "more-human" approach, where they "learn" to handle various situations through training of what is required. Various software technologies, including neural networks, fuzzy-logic and expert systems, can now be applied to solve problems that were difficult to solve mathematically. Of course, all these seemingly intelligent pieces of software must execute on what is still little more than an electronic machine (i.e., the microprocessor or computer) and therefore only form an artificial bridge between the way that humans operate and the way that machines operate. Nevertheless, even if we ignore the glamorous euphemisms, it has to be noted that these techniques are revolutionising the way in which engineering and science function.

In the past, engineers and scientists endeavoured to understand the world by modelling it (usually with mathematics) so that they could then exert some control over it. Eventually, however, there comes a realisation that if mathematics is only one tool for achieving such objectives, and that that tool needs to be applied in a very complex way to solve a problem, then perhaps it is the wrong tool altogether. Computer technology has therefore provided new tools for solving problems and they change the very way in which engineers and scientists have been trained to think. Firstly, there needs to be an acceptance that the real world is often just too complicated to accurately explain using basic science (i.e., mathematics, physics and chemistry). Secondly, there needs to be an acceptance that, as real world problems become more complex, the desire to fully understand them becomes more unrealistic. Thirdly, there needs to be an acceptance of the principle that if it is possible to exert control over real world systems, without fully understanding them (in a mathematical sense), then the focus of engineering and science needs to change from "understanding" to "problem solving".

Many engineers and scientists would find the idea of moving from "understanding" to "problem solving" as heresy and, moreover, we need to consider that the computer tools, that are currently available, are still largely in their infancy. However, the trend is clear. Those that endeavour to spend their lives understanding the concept of fire are not likely to survive a winter, while those who simply accept it and use it to warm themselves are more likely to live and move on to better things, even if there is a risk of getting burnt. Ultimately, a deeper understanding may naturally eventuate but it can no longer be an essential prerequisite for progress. Further, the increased risk of getting burnt (by not fully understanding the world in which we live and the tools which we use) is a penalty that we will need to consider when we apply technology in the future.

The 20th Century not only brought about rapid technical change but it also brought about massive technical problems. These problems largely stemmed from unprecedented population growth, pollution and the diminishment of finite natural resources. In turn, these factors led to the emergence of new diseases, rapid changes to industry, employment and wealth patterns. From a technical perspective, the problems that societies face become more and more complex and the rapidity of their emergence necessitates a need to accelerate the problem solving process. The emergence of the computer, as a generic problem solving tool, is perhaps where the real computer revolution has occurred. Its ability to perform mundane tasks at an increasingly higher speed means that, if we can learn to think in terms of dividing complex problems into many smaller mundane tasks, then the solution to many emerging technical problems is within reach. This, in turn, will require a revolution in the way in which we view problem solving in engineering, medicine, science and, perhaps, even business.

The real revolution in computing is therefore not a technical one. It is a social, industrial and political revolution that has emerged in response to the availability and affordability of useful tools which, in turn, emerged at a time when the world was ready for social and industrial revolution.

The way in which technology impacts upon society therefore largely depends upon the way in which we use it as a tool. If a work-man uses his shovel as a prop to rest upon, then the shovel has little value as a tool. If, on the other hand, the workman uses the shovel for moving soil, then the shovel is a valuable tool that increases the productivity of the work-man.

Prior to the introduction of the pocket calculator, in the 1970s, it was generally accepted that one and one made two. After its introduction, humans lessened their reliance on mental arithmetic and used the calculator as a prop. Many would now accept that, provided the answer was generated by a calculator, then one and one could well equal 587.29 or, perhaps, -345. Perhaps, the world will have to accept that one and one don't always equal two in a technological world. Perhaps, on the other hand, the world will have to accept that progress will ultimately result from the combined use of the best human traits and the best computer traits - in other words, from using technology to do the work of ordinary men, and from using extraordinary men to direct the course of technology.

Has technology dramatically improved business, industry and society?  
It all depends on whether technology is used as a tool or a prop to rest upon.