Inventions and Inventing: Finding Solutions to Practical Problems

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1999

Monograph Series No. 35

THE INSTITUTE FOR CULTURAL RESEARCH

Monograph Series No. 35
This version prepared for free download 2006.
The original hard copy edition:
ISSN 0306 1906 – ISBN 0 904674 27 4 – Published 1999
may be purchased from the address given above, or on the ICR website, www.i-c-r.org.uk

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Note

This monograph derives from a presentation at *Human Solutions: Problem Solving and Society,* a seminar given by the Institute for Cultural Research in January 1998.

Acknowledgement:

The author wishes to thank Ramsay Wood for editorial and stylistic support.

Inventions and Inventing: Finding Solutions to Practical Problems

> God hath made man upright; but they have sought out many inventions. *Ecclesiastes vii 9, (c.250 BC)*

Introduction

While familiar to us in science and engineering, we also use the word ‘invention’ in other creative endeavours such as music, mathematics, fine art and literature. In this broader context we can define invention as the purposeful use of imagination, to satisfy a human need [*see appendix: Art, Science and Creativity*]. Therefore the aspects of invention such as the timing and the underlying mental processes outlined specifically here in relation to science and technology, apply equally to much wider areas of creativity and problem solving.

An essential requirement for an invention is that it be a new idea rather than a modification or reformulation of an existing concept. A more precise criterion for defining novelty in terms of overcoming contradictions is described in the section on the science of inventing.

‘Invention’ is often used synonymously with innovation yet there is an important difference. An innovation is an invention that has been put into practice. Many inventions have the potential to solve practical problems or satisfy human needs, but only when they fulfil this potential do they earn the title of innovation. One example that illustrates the difference is electrical power distribution by Alternating Current (AC). Nikola Tesla invented the poly-phase AC system in 1882 and legally protected his ideas from being copied by filing patents in 1887. A year later the Westinghouse Electric and Manufacturing Company purchased the key patent rights from Tesla, and spent the next few years developing the concepts into an innovative technology making AC power available for street lighting and industrial use.

It was Edison who said “Invention is 10% inspiration and 90% perspiration”, but the perspiration more accurately comes from the effort needed to bring an invention successfully through to innovation. There are currently some 20,000 new patents for inventions taken out in the United Kingdom each year, but only 2% of these new ideas will become commercial innovations.

Given the link of invention to the broader context of creativity, it is hardly surprising to find that many inventors past and present had no background in the fields of science or technology. Indeed many of our greatest inventions came about before the emergence of the modern scientific era in the mid 17th century. A training in science does not automatically confer an ability to invent, in fact reference to the creative process and its application is noticeably absent from the science curriculum even at undergraduate level.

Yet creativity is an essential ingredient in science, and without it there would be little progress. The method of scientific investigation laid down by Bacon, Galileo, Newton and Descartes ushered in the cultural climate that nurtured our subsequent dramatic growth in scientific knowledge and technological know-how. This method was a synthesis of modes of thought and techniques that had been developed earlier and can be generally stated using current terminology as a procedure with these five stages:

1. Proposal of a hypothesis concerning an observed phenomenon.
2. Design of experiments to test the hypothesis.
3. Acquisition and analysis of data from the experiments.
4. Test of the results against the hypothesis.
5. Progress in the understanding of the phenomenon.

Scientific methods, however, do not provide a means for choosing the hypotheses or designing the experiments, and, without some creative input at these stages, progress would be limited to the far slower method of trial and error. For completeness, a sixth stage, again requiring a creative input, was introduced later – that of predictability. This enabled new hypotheses to be devised from the results of investigations on the original ones and resulted in a much faster rate of progress in the understanding and development of modern science and technology.

Despite the need for creativity in scientific education, today most new innovations emerge from the scientific or technological arenas of academia or industry. One aspect in the history of invention is the discovery and fabrication of new materials and the development of techniques for making the best use of them for solving specific problems. The complex materials and fabrication processes in use today require extremely costly, specialised equipment and teams of people with a diversity of skills to produce inventions of modern technologies. The resources of modern scientific institutions and organisations vastly exceed those of any individual enthusiast. Nevertheless, heroic non-specialists working alone with minimal support continue to be a highly productive source of new inventions and they are sometimes ahead of the thinking of large organisations (e.g., Trevor Baylis's clockwork radio and James Dyson's dual-cyclone vacuum cleaner).

Tinkers and Thinkers

It is worth clarifying the relationship between science and technology to add coherence to the following section on the historical highlights of invention. An artificial division that had its origins in ancient Greece still exists between the two fields of science and technology. The latter, being a branch of applied science, is often perceived as a poor cousin to the more honourable pursuit of pure science, where the great discoveries are allegedly made. Indeed, it was recently commented by an eminent scientist and broadcaster that technology progresses by the method of trial and error (a primitive form of science), whereas pure science draws on the great scientific tradition laid down during the 17th century.

A comparative study of published papers from these two fields soon reveals that they speak the same language. Their approaches to research are identical, and though guided by the aforementioned six stages of the 'modern' approach, more often resort to techniques more commonplace in a kitchen. Both also frequently depend on a certain amount of luck and serendipity.

These two fields actually enjoy a symbiotic relationship. Without the technologies that utilise the latest discoveries of pure science, it would be impossible to design the experiments to make further discoveries. Furthermore, many new scientific discoveries have been observed and physical theories devised from the studies of inventions themselves. Here are some examples:

(i) A generalised theory of the electromagnetic properties of matter across a very wide spectrum (x-rays, ultra-violet, visible, infra-red, microwave and radio waves) stemmed from early work on the absorption of radio waves from a transmitter.

(ii) Measurements on the noise limits of early radio receivers led to the discovery of a ubiquitous background of electromagnetic radiation. This was an essential step in the development of the Big-Bang theory of the origins of the universe.*

(iii) The quantum effect known as 'tunneling' was first observed in semiconductor diodes.

(iv) In a more general sense, the invention of lasers opened up the new field of basic research known as quantum electronics. The laser has enabled experiments to be carried out to test some of the unanswered questions of quantum theory.

It is clear from the history of science and technology described next that the adoption of techniques for invention and the influence of inventors themselves, played a vital role in laying down some of the foundations of the methods of modern science.

Historical Perspective

The following is a brief review of the major milestones that led to the development of modern scientific thinking. It is incomplete inasmuch as any history of science must interweave the parallel histories of philosophy, law and religion.

The so-called birth of the modern scientific era generally located in Western Europe during the mid 17th century was not so much the birth of science as the formalisation of an effective scientific procedure; but it was by no means the first one. The organised use of knowledge gained from observations of the habits of animals hunted by early humans was the first deployment of a scientific method. It allowed them by association and intuition to abstract rules, make local generalisations, predictions and to accumulate knowledge.

*Thanks are due to T. Clapp and M. Crown of Nortel Networks for suggesting examples (i) and (ii).

Where there was no observable patterned behaviour of events in the external world, or patterns over which there was no control, superstition was invoked and inter-mixed with this primitive science. This mixture continued more or less throughout history, and much of the progress in scientific thinking was a consequence of the gradual unbundling of superstitious thought and religious influence from the endeavour to understand the physical world.

This early scientific method was applied in other areas of life, enabling the necessary organisation of people and the environment to create the early agricultural settlements and eventually the first civilizations.

The inventions that were produced to meet the changing demands of life, from early hunting weapons to the means of land management, were the result of applying observations made through working with the available raw materials. This was the birth of technology, or in other words, the same scientific method applied to the use of materials and the control of nature.

One striking observation that soon becomes apparent from a study of the early history of invention is that despite the incredible array of technological innovation that surrounds us today, human ingenuity was equal to this at the dawn of early civilization. The only record of early humankind is its inventions. The first creations by anonymous inventors, signalling the gradual transition of the hunter-gatherer populations of pre-history into a more settled and organised argricultural life, include the following:

The use of fire, hunting and fishing, simple weapons, spinning, weaving, bleaching, dyeing, painting, pottery and glazing, house building, embalming, agriculture, domestication of animals, boats, domestic implements, water supply and irrigation.

It is also noteworthy that many of these early inventions were not just invented once, but re-invented at different times and places by different people. Sometimes the gap between re-invention is a few years, sometimes hundreds of years, this time lag being determined by factors described later. Re-invention applies equally in modern times but thanks to modern communication the time lag is somewhat shorter.[1]

The next important development in the history of science was the attempt by the ancient Greeks not only to control the patterns and forces of nature, but to actually understand them, to make global generalisations (theories) and abstract laws at a deeper level. An example of this thinking was the system which described the universe in terms of four basic elements: earth, air, fire and water. This approach, however, was largely a process of intellectualisation based purely on observation and inductive reasoning (i.e., reasoning from particular facts to a general conclusion). Interestingly, experimentation that was to play such a key role in the development of modern science, was not used to test this thinking that would now be called pure rather than applied science. Experimental methods were, however, established by the inventors and craftsmen of this era, albeit by using a cumulative trial and error approach.

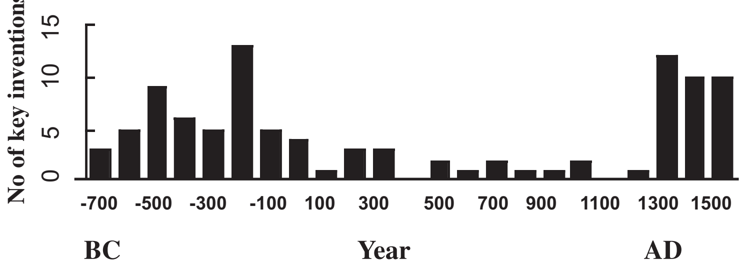
Classical Greek influence extended through to the end of the Roman empire in 333 AD and introduced deductive thinking (i.e., reasoning from a premise or known principle to a specific solution) as first founded by Aristotle (394-322 BC). Mathematics, by which was meant the science of quantification, had, like experimentation, hitherto been regarded as of secondary interest to the rarefied thinking of the philosophers. However, the advances in technology, including developments in transport, weaponry and architecture, relied more and more on mathematical knowledge as well as on the skills of artisans in working with new materials. Reproducibility, an essential element in successful experimentation, was also well established by now in the procedures for fabricating materials and for manufacturing.

With the development of deductive, logical thinking during this period, mathematics was raised to a higher status. It was regarded as a valuable tool for investigating the nature of reality and acquiring knowledge. Speculation borne of imagination was still considered the primary source of knowledge, however, and experimentation was regarded as inferior to the capabilities of the mind to observe and comprehend nature. Nevertheless, apart from the continuity in experimentation by inventors and craftsmen in creating the technologies of this period, some experimentation in the pure sciences was beginning to be undertaken in the fields of astronomy, mechanics and hydrostatics.

Inventions of the past provide important information on a culture's history as well as indications of its stage of development.

This is illustrated quantitatively in Fig 1 for Western Europe where the number of key inventions and discoveries is plotted in the period just preceding the early Greek civilization to the Renaissance.

Fig 1: Key Inventions in Europe – Early Greek period to Renaissance



The flourish of invention from 700 BC to 200 AD signals the growth of the Greek and Roman civilizations, followed by a decline in the middle ages when Western Europe suffered prolonged political instability due to numerous invasions by warring tribes and latterly plague. The scientific and technological knowledge in other cultures continued to flourish during this period particularly in the Middle East and China, greatly surpassing that of Western Europe. The confluence of Arab science with preserved remnants from the Graeco-Roman cultures during the expansion of the Moslem empire into Spain gave the Arabs a world lead in scientific knowledge and technological know-how in this culture.

One example of their inventive achievements during the prolonged dark ages of Western Europe is the work of the Banu Musa – three brothers who lived in Baghdad in the 9th century. In their work entitled *The Book of Ingenious Devices* a number of gadgets were described, some practical and some just for entertainment. A leading expert on medieval Arab engineering, Donald Hill, says this about one of them:

> "Nothing like it is known to have been attempted before or since until the advent of modern pneumatic instrumentation. Indeed they had exhausted the subject, it would have been impossible to emulate them in this kind of construction."[2]

The caliphs of Baghdad made use of the engineering capabilities of the Banu Musa to create the most amazing high-tech theme parks. One report quoted in the book *Ancient Inventions* by Peter James and Nick Thorpe[3] describes a palace built by the caliph:

> "A pond flanked by moving statues of mounted warriors. In the lake was a tree made of silver with mechanical whistling birds of silver and gold. Another pond was made of mercury, on which gold boats floated. The gardens around the ponds were also decorated with automata – singing birds, roaring lions and other moving creatures."

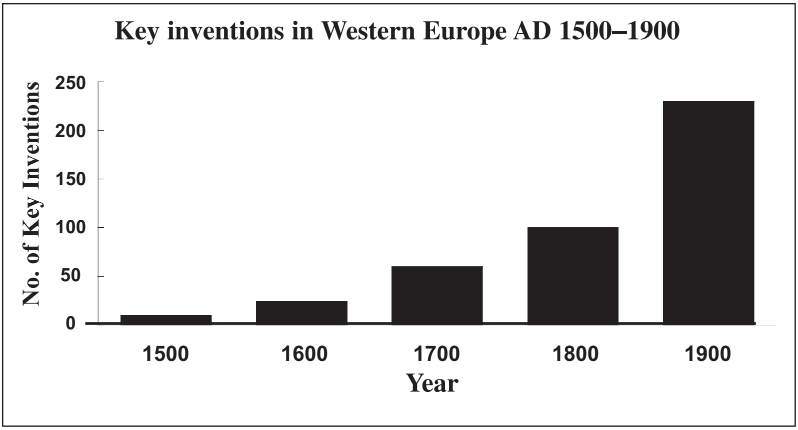
In China during this period great technological achievements also took place, an example being Su Sung's Cosmic Engine built in AD 1090. This was a thirty foot high water-clock which had astronomical instruments on its top and inside there were intricate gearing mechanisms that drove several carousels of wooden puppets. The puppets revolved on the carousels, ringing bells, beating gongs and drums and appearing at windows in the side of the clock structure at regular intervals of time. This whole mechanism was driven by a huge waterwheel and ran for over thirty years.

Despite the amazing technological achievements and breadth of knowledge in these cultures in a number of fields, notably mechanics, medicine and astronomy – the methodology of modern science did not arise in these cultures during this period. The reasons for this are due to a complex mix of religious, legal and philosophical influences in these cultures.[4] However, the transmission of Arab scientific and philosophical knowledge to the West between about 700 and 1400 AD, along with the re-discovery of surviving texts of Greece and Rome by Western scholars, sparked a new revolution in thinking, one branch of which eventually became modern science.

One important rediscovery at this time led to a gradual shift in religious outlook away from the early Christian view that natural phenomena were relatively unimportant compared with spiritual values. This was the view that spiritual Truth could be revealed through actively seeking the underlying patterns in nature.[5] Whilst still a religious view, and it is important to note that the founding fathers of science were deeply religious, it enabled the development of an effective method for scientific investigation and led to the birth of modern science.

The final emergence of ‘modern’ scientific thinking by the efforts of Galileo, Descartes, Bacon and Newton some 350 years ago, was an orderly synthesis of the fragmented elements of observation, deduction, induction and experimentation outlined earlier. The evolution of an investigative technique coupled with the application of inventions for measurement and for further research, led to a very effective means for the acquisition of knowledge of the natural world.

The harnessing of different forms of energy and the application of newly found physical laws by engineers and technologists using the same scientific approach led to the industrial revolution about 100 years later. Fig. 2 shows the accelerated rise in invention and discovery precipitated by these developments.



As more materials were made available through the scientific procedures of discovery and more was understood about their properties and their fundamental nature, chain reactions in technological development were triggered. Within the period of the last 100 years at least four identifiable technological ages have evolved, namely – Electronic, Nuclear, Space and Information. Rather than each age superceding the previous one, they not only continue to develop independently but cross-fertilize, resulting in an even more rapid rate of development. A real sense of the accelerating pace of science and technology is seen if we compare these recent developments with earlier ones. The stone age lasted 2 million years, the copper and bronze age lasted 5000 years and the age that harnessed water and wind lasted 1000 years.

The Timing of Invention

"Time is the greatest innovator" – *Francis Bacon.*

There are four main factors that influence the time when an invention arrives and becomes a succesful innovation. If one or more of these factors is absent the invention is delayed or may never be realised.[6] These are listed below:

1. *Intellectual*: The basic concepts and knowledge must be in circulation for the idea to arise in someone's mind.

2. *Materials and techniques*: Techniques for producing and using the required materials must be available for turning the idea into a reality.

3. *Social*: For the invention to be adopted and considered of value in solving a practical problem, there must be need or use for it in society. Implied in this is a communication between inventors and the culture in which they live.

4. *Economic*: Those involved in inventions and inventing must be able to fund and benefit materially from the development and promotion of their ideas. After a prototype of the invention has been designed, built and tested, techniques for manufacture have to be developed and in the early stages many modifications are necessary, adding further cost and delay to the original invention. Finally there is the cost of marketing, but if the innovation is successful, the rewards can greatly exceed the costs. Delays attributed to the economic factor have affected, and probably always will affect, the timing of innovation since there is always an element of risk in predicting the social climate.

There are many examples in history of delayed inventions that can be attributed to the absence of one or more of these four factors. A few, spanning from Roman times to the modern era, are listed below:

(i) Steam power in the Roman empire

A working model of a steam turbine was invented by Hero of Alexandria in AD 62. Also working inventions using the piston and cylinder, the crank and the valve were demonstrated at that time (albeit in applications of hydraulics). It is feasible that steam power could have been developed during the Roman empire. However, there was no need for large-scale harnessing of natural energy as an abundance of muscle power existed in the form of slave labour to do this work.

(ii) The inventions of Leonardo Da Vinci

Leonardo was a prolific inventor but very few of his inventions were ever constructed. Indeed many went unknown for hundreds of years and in some cases were re-invented. The materials of construction in this period were mainly wood and leather, and it wasn't until much later, when metal-working techniques for the construction of clock and navigational instruments were developed, that some of his inventions could be actualised.

(iii) Pulse Code Modulation (PCM)

PCM revolutionised telecommunications. This is the method by which analogue signals were encoded digitally for transmission over telephone networks. The concept of PCM was invented by Alex Reeves in 1937. If he had tried then to build even a simple form of transmission system which multiplexed voice signals into PCM format, his prototype would have filled up an average size living room because the electronic switch of the day was the valve. It was only when the development of transistors reached maturity in the late 1950's that it was possible to construct a practical PCM system.

(iv) The laser

The laser was invented in America by Shawlow and Townes in 1958. When this invention first arrived it was described as 'a solution looking for a problem' rather like Hero's steam turbine.

However, unlike the latter, it took only a few years before a wide range of applications for the laser were identified.

(v) Aviation
Man-made flight provides us with an example where delay arose from the absence of the appropriate intellectual climate. Whilst the concept of flight had existed in early human-kind's imagination, practical ideas for how this might be achieved didn't begin to arise until the invention of the kite in China in about 400BC.

The Art of Inventing

> "Countless ages will beget many new inventions, but my own is mine" – *Pedanius Dioscorides (c.100 AD)*

Education systems that elevate factual learning above 'hands-on' experience and broadcast lecturing over personal tuition tend to regard creativity as an innate spark possessed by a fortunate few. However, creativity is a human given that can be expressed in many different ways and a successful education is one that enables individuals to both find and express their own creative impulses. Creativity to a limited extent can be taught, but it is most effectively nurtured through working closely alongside other creative individuals.

Four key mental processes for encouraging creative solutions to problem-solving through invention are Abstraction, Analogy, Conceptual Combination and Incubation. Each of these is described separately below:

Abstraction
This is a process of questioning a problem by abstracting back from the specific current solution to a more general approach that highlights the real issues. Suppose we are trying to build a better mousetrap. The obvious thing to do is investigate current designs and try to improve them. However, by abstracting the problem back to fundamentals, we arrive at the fact that the problem is about finding a means of getting rid of mice. This now opens up other options and the possibility of new inventive solutions.

Analogy

Thinking by analogy is a powerful problem-solving technique by which unknown solutions to problems may be imported from other knowledge domains where the solutions exist. The most abundant source of analogical solutions is to be found ready-made in the natural world. Some examples of key inventions made from observations of natural phenomena are given below.

(i) Velcro was invented after George De Mestraal examined the method by which cockleburr seeds were scattered by attaching themselves with small hooks onto the fur of passing animals.

(ii) Float glass was invented by Alistair Pilkington whilst washing the dishes when he observed that small droplets of oil produced a thin perfectly flat film when floating on water.

(iii) René-Antoine Réaumur's observations of wasps constructing a nest by producing a pulp from treebark, led many years later to the invention of paper made from wood pulp.

The eminent architect, Buckminster Fuller, illustrated the power of analogy in his description of a human being:

> "A self-balancing, 88-jointed adapter-base bi-ped: an electrochemical reduction plant with storage batteries of energy extracts for activating thousands of hydraulic pumps, 62,000 miles [100,000 km] of capillaries, self-lubricating crushers and cranes: this whole mechanism guided from a turret containing stereoscopic rangefinders, olfactory and auditory sensors, air-conditioning inlet and exhaust, and a main fuel intake. The whole system needing no servicing for 70 years, if well managed!"

Conceptual Combination

You can't get something from nothing according to a universal law of nature, so it could be questioned at the psychological level whether there is such a thing as an original idea. But something new can be produced from the combination of two previously known but unrelated ideas. For example, in Fig. 3 if we take the two objects separately and then try to combine them, we instantly recognise an upturned hat, but the other object could be one of

Fig 3: Illustration of Conceptual Combination

many things. In seeking a mental pattern for the whole picture we could speculate that the other object could be something being thrown into the hat or possibly a butterfly flying out of it. For the overall image neither of these yields the relaxed state of a solved problem. If we invert the image, however, we instantly find a more creative and satisfying solution – where the two separate objects combine to produce a third new concept (i.e., new in the sense of not being implied by the individual objects) [*see Appendix: Art, Science and Creativity*].

The process of combining two or more apparently unrelated ideas and producing a new third one was named 'bisociation' by Arthur Koestler in his book *The Act of Creation*.[7] In an earlier reference to this creative process the mathematician Poincaré recounted a sleepless night saying:

> "Ideas rose in crowds, I felt them collide until pairs interlocked, so to speak making a stable combination. Among the 'stable combinations' the most fertile will often be those formed of elements drawn from domains that are far apart."

More generally known as conceptual combination, this mental process was believed by Koestler to be not only the basis for creative leaps but for appreciating humour and metaphor.

A classic example for illustrating conceptual combination in the world of inventions is the first printing press, where the inventor, Johann Gutenberg, combined the concept behind the wine press with the coin punch to produce a new invention – a means of creating printed impression on paper.[8] A more recent example is Trevor Baylis's clockwork radio where, again, two unrelated concepts – a clockwork dynamo and a radio receiver are combined to produce a new means of bringing communication to remote areas where electrical power is not readily available.

When an invention comprises a combination of two familiar ideas, such as in the Gutenberg press and the clockwork radio, then a creative scientist is no more likely to arrive at the invention than a creative non-scientist. Hence the continued survival of the artisan inventor.

If one of the concepts to be combined is a physical principle, however, then the idea is more likely to emerge from someone with a knowledge of science. An example of this is the Thermos flask which combines the familiar concept of a bottle-shaped object for holding liquids with the physical principles that heat is reflected from a shiny surface and a vacuum is a poor conductor of heat.

Clearly the greater the scientific knowledge possessed by inventors, the greater their choice of conceptual combination and the wider their range of potential inventions.

Incubation

Creativity cannot be switched on to order and conscious mental activity that solves problems begins as unconscious activity. The incubation time for a solution to arrive in consciousness varies, depending on a hierarchy of innate priorities. Archimedes cry of 'Eureka' in the bath is perhaps the most well known example of an incubated solution to a problem. More recent examples are given below:

(i) An insight for a major invention came to Nikola Tesla when he was reciting poetry while walking with a friend.

(ii) Denis Gabor stopped in the middle of a tennis game saying "I have to write something down" – the something being the invention of holography.

(iii) Harold S. Black invented the concept of negative feedback in an electronic amplifier whilst crossing the Hudson River in a ferry. He wrote his ideas down on the back of the *New York Times*. (Negative feedback in an amplifier is used in every type of communication and control system from radio to automatic pilots, from computers to artificial limbs).

These four aforementioned cognitive processes give some insight into the creative process and even point the way to techniques for improving one's creative ability. However, little is known of the unconscious train of events that lead up to a creative solution to a problem and it surely is there that the creative processes really take place. It is doubtful whether understanding will arrive entirely from physical studies of the brain, given its immense complexity and the crudity of diagnostic measurements. Progress is being made in both a microscopic and macroscopic sense, however, thanks to the relatively new disciplines of neuroscience and cognitive psychology respectively.

The Science of Inventing

In the early 1940's Geinrich Altshuller worked in the former Soviet Union as a patent expert for the Navy. His job was to help others secure patents for their inventions. He was often asked to help in inventing and his curiosity led him to believe there must be an underlying pattern in inventions and problem-solving, and that a systematic technique for inventing could be devised.

To find this pattern he screened some 200,000 different patents coming from a range of industrial areas (automotive, aerospace etc.), looking for how they had solved particular problems. He found that irrespective of the area of application, 32% of these inventions were routine design improvements and a further 45% were minor improvements but with some compromise in the design. 18% of the inventions, however, were fundamental improvements in which a trade-off had been resolved. The next 4% used completely new principles to solve a problem and the remaining 1% represented a breakthrough or new discovery.

Altshuller, on studying inventions in different industries, showed that over 90% of the problems engineers face had been solved somewhere before. It was the third category where a trade-off or contradiction had been resolved that particularly interested him because these required knowledge that would generally be beyond the specialisation of the inventor. Rather like Nasrudin looking for his key under a street-lamp because there's more light there,[9] the inventor seeks solutions to problems within his own field of experience. However, these solutions will not resolve contradictions and always lead to a compromise.

Altshuller found, again irrespective of the industry, that there were 39 standard technical characteristics that cause conflict, such as weight, length, force, strength etc. An example of a contradiction is weight and strength because, in general, if we try to design something that has improved strength we generally make it heavier. If our invention requires it to have reduced weight also, then we have a contradiction which we would normally solve by compromising on both weight and strength.

From the huge database of patents, Altshuller also extracted 40 inventive principles such as segmentation, extraction, inversion etc. To find which inventive principles to use to solve a particular problem, he devised a graphical matrix along the horizontal and vertical axes, of which any two conflicting characteristics could be looked up. In the intersecting cell of the matrix, the appropriate inventive principles are listed.[10]

Altshuller's method of inventing is a very effective shortcut, in that it provides an individual with the results that would otherwise have required a brainstorming session with a team of people having a variety of skills. This technique requires a certain skill in interpreting the inventive principles, though it has been made easier with a software version currently in widespread use in several high-tech companies.

In spite of the effectiveness of this approach to the mechanisation of inventiveness, it is limited to those specific problems that require the resolution of a parametric trade-off.

Predicting the future

> "We must no longer wait for tomorrow – it has to be invented" – *Gaston Berger*

> "The future is not what it used to be" – *Paul Valéry*

In spite of the delays and uncertainties that occur in the arrival of new inventions and innovations described earlier, predicting the short-term future is an important activity for the survival of competitive businesses working in science and technology. The Japanese government pioneered the first 'Foresight' exercise in the early 1970s and since then a number of similar exercises have been conducted in various parts of the world.[11] The results of the Japanese survey showed that about two thirds of the predictions on telecommunications, agriculture, forestry and fisheries were correct but only a quarter of those about energy and life sciences came true.

Longer term predictions, however, are rarely correct. For example, in 1958 it was believed that by the 1990's we would have robot servants, climate control, flying cars, moon colonies, undersea cities, disease-free lives and a twenty-hour working week. More recently it was predicted that we would have paperless offices when in fact we now have five times more paper than before. Some quotes from the past that reflect our inability to estimate the importance of new inventions are given below:

1890: "I have conclusive proof that heavier than air flight is impossible"

Physicist

1874: "The telephone has no practical application"

The Telegrapher

19? : "The telephone is a wonderful thing – every town should have one"

Postmaster General

1943: "I think there is a world market for about 5 computers"

IBM Chairman

1949: "The current design of computer weighs 30 tons. Computers of the future may weigh only 1.5 tons"

Popular Mechanics

1964: "Newspaper distribution pushed through the letterbox will have become a preposterous anachronism in the 1980's"

TV Director

Even though predictions don't often turn out as and when expected, due to the four factors discussed earlier, we constantly benefit from innovations arising from new discoveries that were not predicted. These fresh and unpredicted discoveries are often a by-product from the work in pursuing the original wayward goals.

Recent inventions and technological achievements unforeseen in 1958 would be personal computers, the global information society, public mobile communications, moon landings, artificial organs, gene-splicing, and nano-technology all of which were a result of building on the research in place at the time.

'Necessity is the mother of invention', the saying goes. For many early inventions this was undoubtedly true when inventions provided the means for the survival of a growing population facing a range of unpredictable and often life-threatening natural forces.

In modern times, when many inventions are more focussed on labour-saving, stimulation or convenience, market forces themselves create our need. For many modern innovations a more appropriate phrase would be 'Invention is the mother of necessity'. Interestingly, as concerns are voiced about sustainable growth for the world's exploding population and as our concomitant awareness of ecological issues increases, 'necessity' may again become the key driver for innovations of the future.

As discussed earlier, much of the success in the development of modern science can be attributed to the diminishing influences of superstition and religious ethics. In our time, science has not only largely eliminated these influences but from itself has now expanded further into these territories to re-shape them. Daniel Dennett, an American philosopher, described Darwin's theory of evolution as "the single best idea anyone has ever had", one that had transformed psychology, politics, ethics and religion.

This transformation may be all to the good for providing insights into some aspects of human nature, but it has rather thrown the baby out with the bathwater. The materialistic, reductionist view of nature that is the legacy of modern science, in common with any mode of human perception, is built on assumptions that cannot all be tested from within its own system. These assumptions upon which scientific methodologies stand, have vested science and technology with a belief that it has no limits to its knowledge and exploitative capabilities. The problems that this can create are now becoming abundantly clear.

Paul Valéry commenting on one of these problems – the sense of alienation that has arisen from the power of science – wrote in 1944:

> “Life has become, in short, the object of an experiment of which we can say only one thing – that it tends to estrange us more and more from what we were, or what we think we are, and that is leading us ......we do not know and can by no means imagine where.”[12]

There is no equivalent to the Hippocratic oath in science. In its current mode of operation science has become a very efficient amoral machine for discovery, and technology provides the engine that verifies and exploits its findings. This desire to know because there is something to be known and to exploit wherever possible has solved many problems, but it has also created unprecedented ones.

Sustaining the world’s population in its current mode whilst simultaneously competing for economic success from technology has had a corrosive effect on the natural world. For many short-term economically successful inventions, a greater price has to be paid in the environment in the long term. Ecological issues such as ozone- layer depletion due to chloro-fluoro-carbons and more direct pollution due to a variety of waste materials are technology ‘kick-backs’ stemming from excessive use over the last forty years. Whilst corrective action is now being taken on some of these problems,[13] much more intensified initiatives are needed on a number of fronts to reverse some of the worst effects of technology ‘kick-back’.

Conservation and re-cycling are important initiatives but, though necessary, they are not sufficient to solve the problems of the future. The scientific community has a major role to play in this work in adopting a long term view of the cumulative effects of technology ‘waste’ and to focus efforts on developing technologies that are less harmful to the planet. To sustain these efforts, however, will require more than economic and political arguments. The moral and ethical dimensions need to be re-integrated into science.

Signs of this are appearing at a localised level in industry with the introduction of social responsibility programmes. (A socially responsible enterprise is one that in some way promotes the general welfare and dignity of humanity and is respectful of the earth and its finite resources.) The debate on these issues in the techniques of agriculture, animal husbandry, medicine and genetics has also been raised to effect some change. Objectivity, the hallmark of good science, however, can easily be compromised in favour of political expediency in these debates, for example in the recent BSE crisis in the UK and currently with genetically modified foods.

Technology, whether we like it or not, is here to stay. Human life on earth simply could not be sustained at the current level with the existing political and economic models, without the modern technologies of medicine, agriculture and energy production. But an enormous imbalance in the availability of modern technologies world-wide still exists. Taking telecommunications as an example, with the 'Western' world's current obsession with electronic communication, it is sobering to learn that more than half the world's population has not yet made a telephone call. For example, in India, where the population is 860 million, there are only 7 million telephone lines. This imbalance again raises big issues on curbing future ecological disasters in growing and competing economies.

In spite of the current dangers imposed by science and technology, the benefits to humankind are immeasurably great. Throughout human history inventiveness has always risen to solve the practical problems of the place and time in whatever guise they have appeared. The fact that some of the current problems are the product of inventiveness itself does not detract from the overall aim of this effort to create a better quality of life.

Beyond the purely practical, inventions have provided the means to conduct scientific research that has enabled mankind to know more about the origins of the universe and of life itself. There is a growing number of scientists and technologists who also believe that science will be able to explain the last great mystery – the nature of consciousness itself. Amongst these, many believe that consciousness can even be invented and efforts are forging ahead to achieve this goal with silicon-based technology. (One cannot help but wonder, in the unlikely event of the development of such a machine, whether it would be prompted to attempt the same thing using a different material – say, carbon: maybe this could be a criterion for proof of success!)

It is the view of the author that the results of this work on inventing consciousness could have an important influence on the future of science. Any success in this venture will only raise deeper questions about what it is that is essentially human, and these are questions that can never be answered within a reductionist paradigm. A similar process of diminishing returns on fundamental questions is seen in current studies of the nature of matter and the origins of the universe. Theories in both of these areas have been developed beyond the capabilities of experimental proof. It's not unreasonable to suppose the same problems will arise in the attempts to invent consciousness, given the incredible complexity of the brain and relative simplicity of even the most compact silicon chips.

We have seen earlier that there is a growing need to bring a greater moral and ethical dimension to bear on scientific research and exploitation for our future survival. A justification for this, dependent on international political and economical agreements, however, will always be tenuous and unreliable.

This has already been demonstrated to some extent with the work that is forging ahead on human cloning, in spite of attempts to control it. Change at a more fundamental level of scientific thought is required, and this could come from a greater realisation within science, of the limits of science.

To many people these limits are self-evident, but their existence is unsustainable by scientific argument alone. The aforementioned work on inventing consciousness could indicate a harder limit on what is knowable in science within its current paradigm. Such a limit, if acknowledged by the scientific community, could provide a more permanent re-integration of science with a human moral dimension than any attempts by legislative processes.

Wherever this research leads, there is no doubt that our lives in the future will be influenced more and more by inventions in silicon. Machines will be become faster, smaller and smarter. A well-established rule in technology, known as Moore's law, allows this prediction at least to be made with accuracy.[14] Micro-machined silicon is a new technology that will also have a big impact in the future. Microscopic-sized motors and mechanical devices can be constructed with this technology and many new inventions can be conceived by simply combining these concepts with the capabilities of silicon-based electronics.

Perhaps more than any other age in history, we are uncertain about the future now that we can see within a lifetime a complete technological revolution. Facing a range of new global-sized problems for the future, it can be guaranteed that inventiveness and ingenuity will rise to try and solve them. Beyond that, our curiosity will seek through science and its inventions to know as much as can be known of the infinite knowledge of the natural world. But where this leads us to can be best summed up by the following quote by Sir Arthur Stanley Eddington:

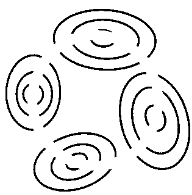
> "We have found a strange footprint on the shores of the unknown. We have devised profound theories, one after another, to account for its origin. At last, we have succeeded in reconstructing the creature that made the footprint. And lo! It is our own."[15]

Appendix: Art, Science and Creativity

Using the terminology of studies on brain hemispherical specialisation, it is tempting to regard science, with its reliance on procedure, repetition and detail, as a dominantly left(ish)* brain, analytical, 'doing' activity. The arts on the other hand are often perceived as a dominantly right(ish) brain, holistic, 'being' activity, essentially subjective, imaginative and emotive. However, artistic and scientific work both depend strongly on both modes of activity.

The common ground is creativity which may be viewed as an interaction between these two modes of thought. Science is creative activity limited by the laws of nature. Logic only appears as such in retrospect, but the thinking that progresses one logical step to the next is in itself a creative act. Art is creativity limited by the imaginative capacity to communicate the spectrum of human experience through different media. Without the tools for expression, the poet and painter would be unable to communicate. Without the metaphors of nature and the culture in which he or she lives, the scientist would lack the imagination to create scientific hypotheses.

A simple model of creative problem-solving is based on viewing mental perceptions as patterns (or hypotheses), which in a neurological sense they are. The problem to be solved represents an incomplete pattern in the mind, and to solve it many other patterns and combinations of patterns are recalled from memories of our knowledge and experiences. These created combinations are mapped onto the incomplete pattern in the mind until an acceptable analogical match occurs that also fills in the gap. In this process it makes no difference whether we are trying to create a poem or invent a better mousetrap. As an analogy, the unfinished ellipses in the figure below represent an unsolved problem. This is solved by perceiving a circular ring which itself is not physically present.



* Recent research has shown that specific mental activity is not as clearly localised in the brain as was originally thought.

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11. For information on the current UK Foresight initiative see: http://www.dti.org.uk
12. Valéry, Paul. *'Unpredictability', History and Politics* (Trans. Denise Folliot and Jackson Matthews), New York: Pantheon, 1962.
13. For example, global conferences such as the Earth Summits held since 1992 to seek world-wide agreement on the control of issues such as greenhouse gas emission.
14. Moore's law, which has been shown to be true since 1971, states that computer processing power doubles roughly every eighteen months. This is largely due to the development of techniques for integrating more and more logic devices per unit area on silicon wafers.
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