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pp.127-135

Return to CONTENTS

Does Technology Need Science?

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INTRODUCTION

Science and Technology have always had an ambivalent relationship. Recent questioning over funding, usefulness to technology, and appropriate priorities in Science is only the latest, but is perhaps the most vocal, period of discussion over the last century in Australia. The aim of this paper is to identify some of the issues and, based on the author's personal background and interests, survey science and technology in Australia both now and over those last one hundred years. The resulting view leads to the need for hard decision making and change.

DEFINITIONS

Science, basic science, is often presented as pure, as a spirit of enquiry, exploring the workings of Nature by postulation and experiment in order to arrive at a description or understanding of how Nature works. The resulting theories aim to simplify the description of the world around us by their elegance and their power to predict the results of experiments. The results of the research, the Science, belongs to the world and is traditionally assessed by its rapid publication in the open literature. James Watson, in his book "The Double Helix" provides a candid insight to the motivations and rewards of basic science at its best, a thrill and drive the author was able, in a small way, to feel in the 1967 discovery of pulsars in the Cavendish Laboratory, Cambridge.

Technology is quite different. Technology aims to exploit the workings of Nature, to set up an environment in which the rules of Nature are structured to achieve an action or result which is of USE. The product is designed to enhance the environment in which we live. Very often the product is designed to make MONEY for the person who makes it. Technology has its own rewards – often financial but also in the self-satisfaction one has in influencing the environment, the way we live. We remind ourselves of Alvin Toffler's definition that technology was developed to meet one of two criteria: "Does it make a buck or a big bang?"

There we see the nub of it all. Basic Science is as pure as the driven snow, increasingly costly but without concern for cost, a pursuit of the spirit with rewards measured by self-satisfaction, peer group esteem, by Nobel Prizes. Technology, on the other hand, is sullied by material aspects, by exploitation, by money. Both, however, have a profound influence on us as civilised beings, removing mysticism from our view of the world, increasing our capacity to control our environment, our fate.

ORIGINS

In Australia distinctions between science and technology seem drawn more strongly than elsewhere. In Australia there seems to be a difficulty in finding the relative and complementary roles that science and technology can play in the pursuit of prosperity and progress, in the pursuit of our cultural development and civilisation.

Australian technology has a popular image quite intimately linked to the heavy metal trades industries whose origins are in the central area of Britain and which formed the core of the Industrial Revolution. We associate that consciously or unconsciously with the working class. Yet Brunel, Stevenson, Trevithick, Wilkinson, Brindley and other great names of the Industrial Revolution belie that working class image even though they were still not part of the establishment, not part of the Royal Society, Oxford, Cambridge and Edinburgh circle. Because in that circle one has definitely entered the arena of basic science, of curiosity in Nature, of leisure time derived from wealth in which to follow academic pursuits. In that circle one finds the origins of our Australian view of science.

A middle ground between these groups did however exist but was centred at none of the places mentioned so far. Faraday at the Royal Institution in London, Wheatstone at King's College London and especially William Thomson (Lord Kelvin) in Glasgow were to some extent different from the others. These were the ones who translated the theoretical observations of Maxwell and Rayleigh into useful products, to motors, generators, communications signalling systems and the first trans-Atlantic cable in 1866. For there was at that time a need to translate the results of the theoreticians to a form suitable for application and the success of the British engineer Oliver Heaviside in doing so without extensive formal education is of significance. Here then was technological transfer in operation just over one hundred years ago – a two way flow of ideas as science was translated to applications and as Maxwell's theoretical work benefited so much from the practical "lines-of-force" ideas of Faraday.

The examples I have used are based on physics and electrical engineering although similar stories could be told of other areas of science. For example the fundamental observations of the science of chemistry had perhaps their most effective and dramatic (even explosive!) transfer into technology in Germany. The history of BASF (amongst others) highlights a most successful and complementary role of science and technology. The chemists Care, Brunk and Glaser in the 1870s introduced scientific methods to production control and began research in BASF. The five chemists in BASF in 1870 grew to 61 by 1884. Whereas only a short time before this chemistry had been regarded as nothing more than an unremunerative trade for eccentrics, one sees just a decade or so later numerous people choosing it as a new and promising career. The development of the dyes in BASF was also achieved by a close and personal relationship between the industry and the academic community of chemists. An extensive collection of correspondence survives to attest to this.

Our questioning and discussions today are not then focussed on chemistry. They are indeed focussed on physics because, as we will see, it is the technology based on physical principles which is the vanguard of the recent technological thrust, it is physics within science which has had greatest difficulty in coming to grips with its technological or "practical" relation.

Today we celebrate a centenary and it is appropriate to concentrate on the decades around 1885 to really see if things have changed all that much. As a contrast to Australia, consider developments in science and technology in the United States of America where, for example, one finds in 1883, the foundation professor of physics at the Johns Hopkins University, Henry

Rowland, announcing in his vice-presidential address to the American Association for the Advancement of Science that the word "science" should no longer be applied to the telegraph, telephone, electric light and electric motor. The earlier English developments had not drawn any such distinction between the science and the technology of new fields of electricity and magnetism. The American physicist could now choose theoretical or practical. In the universities the training in electricity and magnetism was carried out in the physics schools with the students making the choice between a training for industry or in science (usually as a teacher). The separate discipline of electrical engineering was to grow then out of the physics schools over the following decades. Electrical engineering was then, even a hundred years ago, in a different position from the other branches of engineering. Mechanical engineering was, and is, the closest branch of engineering but never took the opportunity to build on the developments in electric motors and generators. Electrical engineering, and all the technology it spawned began in physics, then separated from it, and left behind an emasculated and struggling scientific discipline without a major role or purpose.

The popular imagination had been aroused by the inventiveness (in commercial rather than academic surroundings) of Bell, Edison and Tesla, and electrical engineering flourished – much to the chagrin of the physics schools which had poor laboratory facilities, had to teach these students and see only a small percentage of the students stay to follow the "pure" science path. The spread of use of electricity throughout commerce and society was seen as a most strong utilitarian justification of physics and tied in well with the American passion for practicality.

The supporters of basic or pure research, proud of their stand for cultural advance, and convinced of the nobleness of their cause, were under threat. John Tyndall went on lecture tours in the 1870s pleading for support of pure research. Simon Newcomb, the astronomer, deplored and bemoaned the low levels of national funding of pure research in 1876. Then in 1883, just 102 years ago, Henry Rowland delivered to the American AAAS his talk entitled simply "Plea for Pure Science".

This group of researchers, using arguments about the long term utilitarian worth of pure research but motivated by the classical pursuit of truth, were overtaken. The practical fruits of physics were pursued with vigour. Gilman, the president of Johns Hopkins proclaimed in 1882 that electricity had "wrought greater changes in commerce than the discovery of the passage around the Cape; greater modifications in domestic life than any invention since the days of Gutenburg."

The final blow came towards the end of the last century when the newly separated electrical engineering schools began to question the role of physics education to their curricula. In a discussion still proceeding, only the relevant parts of physics were to be taught and often had to be taught by the engineers themselves with an approach which typified the split which had developed between the newly spawned offspring and its parent. For the physics programme was found to be less and less concerned with the physical areas which formed the basis of the rapidly developing technology.

Chemistry had spawned its applications through chemical engineering, biology through medicine. But in both these cases the originator survived in a way that physics was unable to. It took well into the twentieth century for physics to reassert itself as a discipline in science and to the mid-twentieth century before it reached its peak of eminence amongst the sciences. Yet even then, the loss of its most powerful area of application to electrical engineering had left it isolated in the realm of "pure" science. It is a dilemma which we are addressing today.

So a century ago one sees the same discussions, fears and developments in the U.S.A. as one sees here in Australia today. An emphasis on utilitarianism, the questioning of the value of pure science, the struggle of pure science for funding, are all of current concern. But before dealing in detail with today, we should look back at our own past, at Australia of the 1870s and 80s. For there we can also find experiences, arguments and attitudes well recognisable today, so well entrenched as to be the barrier to the technological changes being sought.

AUSTRALIAN SCIENCE

The development of science in Australia is linked closely to this University, and to the Royal Society of New South Wales. In the Inaugural Address to this Society on July 9, 1867, the role of science in Australia was clearly stated. Reverend William Branwhite Clarke (an original Fellow of St. Paul's College here at Sydney and a pioneer geologist) said that "We have in this Colony a vast region, much of which is still untrodden ground. We have, as it were, a heaven for astronomy and a new earth for geology. We have climatic conditions of the atmosphere, which are not to be viewed by us merely as phenomena interesting to the meteorologist. We have facts to accumulate relating to Droughts and Floods which have deep financial and social importance. We have a superficial area which may engage the attention of Surveyors, Agriculturalists, and Engineers for years to come. We have unrevealed magazines of mineral wealth in which Chemists and Miners may find employment for ages after we shall have mingled with our parent earth."

Through the periods of Clarke, Russell, Liversidge and Edgeworth David; through the Royal Society of N.S.W., Australian Association for the Advancement of Science (to become ANZAAS in 1930), CSIR (CSIRO), and the Academy of Science one sees these same areas as unchanged fields for study, pursuit and for funding. In a unique way Australia was able to isolate its science from the physics developments of overseas, from the utilitarian application of physics so evident in Britain, U.S.A. and Germany. The doyens of Science of the last 100 years in Australia are epitomised by Edgeworth David of whom an obituary wrote

> "Science was to him the eager quest for truth, a joyous adventure in which fresh wonders and delights were ever appearing to reward the diligent searcher."

Several Presidents of the Royal Society of New South Wales (amongst others) were aware of these limiting trends. C.O. Burge in 1904 lamented the lack of appreciation by Government and the people of the practical importance of science and commented that if one did not appreciate this we may be
"rudely awakened from self complacency by some crushing loss in trading or in war."

That shattering of our self complacency is the basis of our current debate, our current reassessments and our current challenge.

AUSTRALIAN TECHNOLOGY

Despite the particular emphasis found in Australian science, which ignored applications of physics, technology was introduced rapidly to Australia. As early as 1863 battery driven arc lamps were set up at Sydney Observatory as part of the celebrations of the marriage of the Prince of Wales. In 1878 arc lamps enabled night-time construction to proceed on the new exhibition buildings.

In 1882, only four years after the world's first street lighting was set up on the Avenue de l'Opera in Paris, permanent electric lights were placed at the Redfern railway terminus driven from a small generator. Six years later, Tamworth became the first city council in the southern hemisphere to set up an electricity supply service when, for 300 pounds, it imported an 18 kilowatt Crompton and Co. generator from Birmingham to light 150 filament and 4 arc lamps.

There was not much science in this and really, not much electrical engineering. The technology and know-how was fully imported and it was a technology built more upon qualitative understanding and empirical rules rather than the exact and scientific approach. It was a technology not appropriately supported within our universities.

The developments overseas in electricity and magnetism spread quickly. Those of communications by morse code and cables spread so readily to a continent dominated by isolation and geographical spread. By the 1870s an extensive cable and telegraph system was in place. Onto this system could be placed the telephone and in the century old story of Australia's telephones are some lessons very relevant to our current concerns over technology and science.

The telephone was first demonstrated by Alexander Graham Bell on 10 March, 1876. As early as 1877 in Australia, following the arrival of several detailed journal articles, W.J. Thomas (a customs agent in Geelong) had linked several houses together with home constructed telephones. By the following year systems had been constructed – all with home made equipment, in Tasmania (by a medical practitioner) and in Brisbane.

Of most note was Henry Sutton who, in Ballarat at the age of 21, had devised and constructed over twenty different versions of telephones and who made the classical Australian mistake. He thought his discoveries "should benefit other workers in science". In the end sixteen of his designs were patented overseas by others. Little wonder that Bell, on his 1910 visit to Australia, made an especial trip to Ballarat.

Not all made the same mistake. J.E. Edwards was a notable inventor and entrepreneur who emigrated from London in 1866 as an experienced telegrapher and electrical constructor. His invention of the "division bells" for houses of parliament came while still in the telegraph department. Edwards is a good role model for today as he set up his own company to manufacture relays and signalling equipment for the Victorian Railways in 1877. The following year he followed a childhood dream and patented his ideas on sending music and voice by wire. He made and sold telephones of his own design until closing his company in 1885. One hundred years ago!

So one hundred years ago we had an information technology industry, flourishing and producing the most recent of technological developments. The industry was locally owned, the technology locally controlled and managed. What went wrong over the following 10,0 years?

But that is another story - the lesson for today is that the telephone developments were, in general, quite separate from science in Australia and this holds several lessons for us as we argue today the relative positions of science and technology.

TODAY

With that as a background, let us now address more closely the current question of whether technology needs science and, more importantly, if the answer is yes then what sort and how much.

The key to answering our question is to ask whether one of two views is most appropriate. The first view is that pure science, generated from basic research, provides new insights to Nature and hence new opportunities to exploit those insights as technology. The second view is that technology develops mainly from technology and only occasionally does an input from science make a significant shift in technology.

Indeed, it is often the technology which drives and extends science, both by generating questions about nature answerable by the classic scientific approach and by provision of extensive instrumentation without which the basic questions in science could never be addressed.

It may be that the wrong questions in science have been asked. One comes back to motivation and just one example will be given to illustrate my theme. A success story in Australian science is its contribution to radioastronomy using innovative and pioneering instrumentation. A common justification of funds for radioastronomy is that it will have practical spinoffs into technology and in techniques for communication. I would rather see the attitude and motivation in Australia which says that if we developed a strong and vigorous communications industry, we would be ideally set up to build and afford the instruments needed for radioastronomy. If commercial success is the criterion to use then science and technology need each other only in so far as they affect the outcome in the market place. For arguments between science and technology are for nought if it is the wealth and living standards of a country which drive us. Commercial and marketing factors must he considered concurrently with science and technology if one is to understand their interrelationship. This consideration is what I call engineering and perhaps one has revealed at long last the real message of this talk. For engineering deals with humans and human-sized problems – it affects the human environment and the human style of living. Basic science on the other hand or nuclear physics and high energy particle physics on the other. It is as one moves away from the human scale using instrumentation which is in itself extreme, that the contributory links to technology and engineering weaken. Such work cannot be judged on commercial grounds and should be judged and valued in context – as the contribution to world science, to the world's understanding of Nature, to civilisation. But the trap is to transfer the same attitudes and concepts about science to the area of human scale. For there the links to technology, to engineering, to commercialisation are stronger and demand different motivations, different attitudes, different skills.

We have been sidetracked and blinded by the chosen traditions for our science in Australia. Physics has never taken the path over the last hundred years as it did in the U.S.A. and Europe. We have had our science dominated by other areas and we have not absorbed the lessons available in the world around us. For these lessons are there and have been there. We need only look to our north, to the developing nations on the Pacific basin to learn.

OUR NEIGHBOURS

Despite the dramatic levels of engineering development and technological productivity, science has not been strong in Japan, Korea, Singapore and the other rapidly developing technological societies to our North if one uses our criteria of Nobel prizes, papers published per capita, or even patents issued.

Japanese technological success is based upon bought technology. Over three decades Japan methodically has bought licence rights to the foreign technology it needs. This was, in the main, the vast bulk of the new technologies developed in the United States since the 1950s. The accumulated cost for acquisition of all this technology is only 15 billion dollars. A most efficient way for a country to build up its technology – much cheaper than a grand scheme of local invention and re-invention.

This cost for technology does not include the free contribution of ideas and technologies available to all in the published literature – the results of a misguided concept of contribution to world science in contrast with and alien to the concept of technological development.

Since the period 1951 to 1954 when Japan imported 100 times as much technological ideas than it exported, one now has the situation where the imbalance has been removed, where patents are as common as in other large industrial countries, where amounts spent on industrial research and development are higher than in the U.S.A. and Germany. Clearly, technology is building on technology (as it can in a position of economic strength) and Japan is increasingly willing and able to undertake its share of contribution to world science, to the very long term future.

Much of this change is due to the clearly stated set of national goals to which the somewhat more rigidly structured Japanese society responds. The country has a consensus about the future, a general agreement about what are the critical sectors for development. The country is agreed on a 'technology-oriented nation' as its future with emphasis on a 10 year programme to develop new technologies for nextgeneration industries. The focus is on three fields: new industrial materials, information processing and biotechnology.

Because of its relevance to the discussion of this paper it is important to outline in more detail these areas. Biological science and technology in Australia have already developed an appropriate relationship. But in industrial materials one is talking of ceramics, synthetic membranes, advanced composite materials, electrically conductive polymeric materials, advanced alloys and engineering plastics The work on these topics is not to be found in many of the Australian physics schools depite the physical nature of the problems. The research work on these areas is in the engineering schools. In the third area, information processing, one enters a whole new field of development worthy of long discussion in itself but able to be put into perspective by "The Industrial Tree" in which the new areas are represented as the Quaternary sector of industry, a completely new sector divorced from much of existing engineering technology. Even more to be appreciated is the way that this technology is utterly and completely dependent on human interfaces for its application and usefulness. Whereas a bridge, dam or mechanical device is functional without human interface, the knowledge industry must involve human factors quite alien to the existing areas of technology and the science from which it has developed.

OUR FUTURE

Let us try then to draw together the strands of our discussion to identify the appropriate roles for science and technology. Australia is a small country whose size suggests it should contribute 5% to the world's science and technology. The immediate implication of that is that we expect to have to import 95% of our science and technology needs. Thus science as a basis to technological R&D must be placed in a very low priority when compared with the engineering needs to take existing technology and engineer it into the products and services which provide the wealth we all desire. There already exists much of the technology and science we need to support our industrial development. Further technology must come from extending the limits of products already in manufacture.

Australia still needs a large number of very skilled people if a technological society is to develop. But to quote L.M. Branscomb of IBM, "The critical fields, I think, are electrical engineering, applied mathematics, computer science, information systems management and manufacturing systems engineering and, if one gets into the basic technologies, very importantly, the materials science, in particular ceramics, polymers and surface physics and chemistry."

My views are then becoming clear. I do not see that science in Australia supports the technologies to anywhere the level and style which I feel is appropriate. Science has backed away from the areas of critical importance to the technologies, from areas which are invariably complex, messy, often mundane, certainly not glamorous but which are, nevertheless extremely challenging. I refer to many areas but would offer the following short list as illustration.

> heat flow and mixing in turbulence
> structures and properties in new ceramics
> physics and chemistry of the blast furnace
> processes in injection and other moulding
> properties and failure modes in composite materials
> material properties and flows in warm-forging

Distinctions in science as regards motivation and style need to be made in ways not as yet done in Australia. Technology is of a human scale, is driven by attention to the limits and edges of current technology, is invariably involved with the cost of the processes, and is often dealing with intractible and difficult areas of science. It is invariably concerned with interaction with humans.

Of course, science is needed. It forms the cultural base on which we will understand the technology, place it in perspective, and resolve our conflicts brought upon us by technological change. Science is necessary in its own right, and offers a unique opportunity to the human race to understand its environment and purpose. It is intimately linked to the philosophy of science and as it explores the most distant of the edges of nature it is able to contribute to the cultural development of humanity and to our civilization.

Needless to say I am therefore in conflict with current attitudes in much of our scientific community, be it Universities or CSIRO, and in conflict with the view of the Minister of Science, Barry Jones. For he has not made the distinctions I have, has ignored the true role that physics, in particular, plays and has not recognised that the overwhelming need is for product development skills, for management skills, for entrepreneural skills. These will not, in general, come from attempted conversion of scientists built up with over a century of adherence to a local scientific basis totally inappropriate for a technologically strong Australia.

The problem therefore does not all lie in a relationship between science and technology. It lies in a crying need to educate and prepare a nation FOR technological change. It does not lie in the creation of bodies to study the impact OF change. We need a concensus view of the future LED by well structured plans and decisions.

We need to do something – the penalty of doing nothing is too extreme. That something is achieveable by clearly stated national goals – a clear long term policy for Australia to manage its own technology. To buy if necessary, to implement systems using it, to sell these systems here and overseas, to build the technology and science base to support this wealth creating operation. We may then reach the point where we can better afford to take our proper share of the load of world science, of the basic science which marks us out as a nation with faith in mankind, with admiration for nature, which is civilised, and which has a true wonder but yet confidence in the rapid and dramatic changes which technology will bring upon us.

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Return to Top