Article 1.1

DISCOVERING AND DOING: SCIENCE AND TECHNOLOGY, AN INTRODUCTION

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> **téchnophób|ia** *n.* (Morbid) fear of or aversion to technology, which is the application of science or the practical or industrial art(s).

My purpose in this chapter is twofold: to explain what science and technology are and how they are related to each other and to the social systems in which they are embedded, and to overcome to some degree the technophobia and alienation from science and technology that many people, particularly women, feel. The attitude held by many women and some men towards increasingly common devices like microwave ovens and video recorders provides an example. Such machines can provide a great deal of flexibility – for example, video recorders can be used to record a favourite television programme for viewing at a more convenient time – but users often find themselves frustrated by the difficulty of operating the machine. This is often a problem of the 'interface' between the machine and the user: frequently the tasks that the instructions require the user to do ('press the time button twice in quick succession, then enter the hour in 24-hour mode by pressing the set button until the correct hour appears on the display. . .') do not match what the user wants to do ('record the programme on BBC2 that starts at 8.20 pm'). The designer has made the interface convenient to the machine rather than its user. As a result, the users may transfer their feelings of frustration and alienation to 'technology' in general. This is more true of women than of men because men may be too embarrassed to admit that they cannot operate a machine and will keep trying. Often feelings of frustration and antipathy for technology are transferred by implication to science as well – isn't it science that gives us high technology? Isn't it science that promises so much and in the end apparently gives so little?

In reading about science and technology, it is easy to be put off because the terms used are 'scientific'. Many people find such terms not only beyond their immediate understanding but even beyond their ability to 'find out'. To help overcome this feeling I have deliberately not explained some of the terms I use because I know they are in general dictionaries. I hope to convince you that because a term is 'scientific' does not mean that it cannot be found in an ordinary dictionary. The term *technophobia* is not, by the way, in my dictionary, but *technology* and *phobia* are, so I combined them.

WHAT IS SCIENCE?

Science assumes a measurable, material world. It is based on the activities of observation, reason, structured experimentation in which phenomena are repeated as often as necessary, and finally, on peer review of results (hence the importance in science of publication). Science does not, however, make claims to certainty.

> The scientist has a lot of experience with ignorance and doubt and uncertainty, and this experience is of very great importance, I think . . . We have found . . . that in order to progress we must recognize our ignorance and leave room for doubt. Scientific knowledge is a body of statements of varying degrees of certainty – some most unsure, some nearly sure, but none *absolutely* certain.
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> *(Feynman, 1988, p. 245)*

It is a common notion that science lacks any spiritual and emotional dimension. Its emphasis on rational thought and logical inference and deduction, and its need to be able to repeat phenomena in order to test them, appear to devalue the emotional, the intuitive, the spiritual and the unique. Yet discoveries early in this century in physics, followed by insights emerging from ethology[1] and ecology, can imbue science with a profoundly spiritual life view.

> The world view emerging from modern physics can be characterized by words like organic, holistic and ecological . . . The universe is no longer seen as a machine, made up of a multitude of objects, but has to be pictured as one indivisible, dynamic whole whose parts are essentially interrelated and can be understood only as patterns of a cosmic process . . . Many physicists, brought up, as I was, in a tradition that associates mysticism with things vague, mysterious and highly unscientific, were shocked at having their ideas compared to those of mystics.
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> *(Capra, 1982, p. 66)*

The older 'scientific' view is essentially mechanistic – nature is seen as machine-like. Natural phenomena can be analysed into their constituent parts and these parts can be arranged according to causal laws. It is like looking at an old-fashioned watch. There is a spring that can be tightened, thus storing energy that can be released over time by allowing the spring gradually to unwind. The unwinding of the spring turns a cog-wheel that turns other cog-wheels causing the hands of the watch to move around its face in a measured fashion. When the spring has fully unwound, the system has no further energy to move any of its parts and the watch stops until some external agent winds the spring up again. A mechanistic model can be applied to classical physics very satisfactorily and can be very easily studied through the application of mathematics. By 'disassembling' a phenomenon to its constituent parts and seeing what causal laws drive each of the parts, we can come to an understanding of nature.

It is this view that has been seen as a particularly masculine view and therefore opposed to a feminine view because of the ingrained practice of gendering modes of thought, modes of reaction to the world around us and modes of working. It is the view that science is comprehensible only by the intellect using objectivity and reason that has labelled science as a masculine activity.

> Feminist scholars have called attention to the many ways our conception of science is tied up with our conception of masculinity. Modern science, they argue, is based on a division of emotional and intellectual labour in which objectivity, reason and 'mind' are cast as male and subjectivity, feeling and 'nature' are cast as female. In this genderization of the world, it seems 'natural' to describe science as a 'marriage' between mind and nature – a marriage celebrating not so much union between mind and nature, but a radical separation of subject and object and, ultimately, the dominion of mind over nature. The result is a particular conception of science – one that seems more suited to men than to women.
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> *(Fox Keller, 1984, p. 45)*

This is reflected in the division of science into a proliferating number of specialisms, in which the scientist spends more and more time looking at smaller and smaller parts of nature. While what follows is a simplification, the changing and expanding terminology of science shows the increasing tendency to split larger units of study into ever smaller units: what was known as natural philosophy gradually became science and science divided into physics and chemistry on the one hand (dealing with inanimate nature) and natural history (dealing with the Earth and animate nature) on the other. Then chemistry subdivided into inorganic and organic chemistry and joined another stream of thought, the biology that descended from natural history, to produce biochemistry and molecular biology. Natural history became palaeontology, geology and biology (life), the last subsequently splitting into zoology (animals) and botany (plants), with zoology then dividing further into icthyology (fish), herpetology (reptiles), mammalogy (mammals) and so on as study was divided along finer and finer lines.

However, many scientists eschew the notion of a single ideology and the notion that the mind can achieve dominion over nature. Capra (1982) believes that the scientific paradigm is shifting to a model which is less mechanical and more holistic. For example, James Lovelock, with Lynn Margulis, a microbiologist, has developed the Gaia hypothesis: this is that the Earth can be viewed as a living organism, that life alters the planet's atmosphere to maintain its continued existence. Lovelock's book (1979) often surprises because it is a detailed scientific treatise and not the tract it is sometimes supposed to be. The Gaia hypothesis has considerable influence in areas such as tropospheric science (that is, the study of the lower levels of the Earth's atmosphere) and it has spawned new areas of study incorporating formerly separate disciplines, for example geophysiology. 'Some scientists who have started listening to Lovelock think Gaia is less important as a concrete theory than as a new paradigm' (Lyman, 1989).

Trying to pin science to a single ideology in the last quarter of the twentieth century is like trying to capture a moving image in text. While many scientists adhere to a belief in the older mechanistic paradigm (which, it should be noted, remains a useful paradigm yielding valid results and providing a valid basis for acquiring detailed knowledge in many spheres), many others are coming to recognize that modern, Western science and technology have not always followed a smooth path of increasing progress and enlightenment; they are seeking new paradigms which will begin to re-integrate scientific knowledge into a holistic view of nature:

> . . . modern physics has not only invalidated the classical ideal of an objective description of nature but has also challenged the myth of a value-free science. The patterns scientists observe in nature are intimately connected with the patterns of their minds; with their concepts, thoughts, and values . . . Although much of their detailed research will not depend explicitly on their value system, the larger paradigm within which this research is pursued will never be value-free. Scientists, therefore, are responsible for their research not only intellectually but also morally.
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> *(Capra, 1982, p. 77)*

Science is as old as speculation and the transmission of knowledge. Until near the end of the eighteenth century it contributed little to either technology or most people's daily lives, though it has always called upon technology to help it develop its instruments. It was an activity confined largely to priests, sages, teachers and only later (in the eighteenth century particularly) to wealthy dilettantes. In the nineteenth and twentieth centuries the practice of science passed to professional scientists in universities and latterly in governmental and industrial research laboratories.

In the West, when we talk about 'science' we mean modern, Western science. We think of it as culturally universal and impartial, and '. . . these assumptions are so pervasive that we hardly notice them, much less question them' (Williams, 1990). Levidow argues that Western science 'embodies values appropriate to capitalism' (1988, p. 101) and that our science was stolen from and supplants other sciences, primarily the Greek model developed and amplified in Arabic science, and Eastern sciences developed primarily in the Indian subcontinent. He argues that Western science expropriated these Eastern sciences and then denigrated, destroyed or denied their sources.

Europeans considered themselves superior from the time they 'discovered' other cultures. However, the measure of superiority has gradually changed from general criteria (including, for example, physical appearance, social customs) to material self-improvement by means of science and technology (the eighteenth century), to 'them' and 'us' divisions based on the opposition of 'progressive' and 'traditional', West and East, and even non-white and white (the nineteenth century). In the twentieth century, struggles for national liberation and reaction to Nazi atrocities have discredited racist arguments for Western superiority, but arguments based on material superiority have remained and been strengthened.

The transformation of science in the West to what we know as modern science (and what we now think of as science) came about as a result of the development and rigorous application of the experimental approach, when ordinary, if painstaking, observation of a phenomenon came to be deemed insufficient to explain cause and effect relationships. Phenomena had to be repeatable, and repeatedly observed, under conditions which clarified the relationships between a possible cause and the effect observed – experimental science.

An example that provides an interesting perspective on this experimental approach and on its subsequent influence on technology is the development of the ploughshare. Over centuries in Europe the development of the ploughshare was a slow process, and when better designs were developed, usually by individual smiths seeking to address local conditions and requirements, the dissemination of information about plough design and the necessary design skills was slow. It was not until the late eighteenth and early nineteenth centuries that *systematic* experiments took place in which one aspect of the design of a ploughshare was varied and tried until a body of knowledge existed about the possible designs of ploughshares and how different designs behaved in different conditions (heavy soil, light soil, wet and dry, initial cultivation and recultivation and so on). By then, the dissemination of designs and skills had come to depend on a literate public with access to mass-produced sources of technical and scientific information and occurred far more rapidly than was possible under the localized master–apprentice system of knowledge transfer.

Master and *apprentice* are legal terms, limited to men; the relationship was defined by a contract, and only boys could be apprenticed. The master agreed to house and teach, the apprentice to provide labour and to learn. A qualified apprentice became a journeyman (sic), usually practising his trade as an itinerant. When he found a place and sufficient money to settle and develop his own atelier, he could become a master in his turn. Girls similarly learned by practical example and practice from an older woman, usually a mother or other adult female relative, and similarly supplied labour, but the relationship was not a legal one; girls did not become 'journeywomen', but often married into the same trade as their father practised and contributed significantly – but informally – to its execution. Women sometimes became masters, but only as a result of being the widow or daughter of a deceased master, not in their own right.

Science was originally a rather solitary occupation. Scientific societies such as the Royal Society gathered, disseminated and published information and provided a forum for the interchange of ideas. They began in earnest in the seventeenth century. They excluded women because they reflected the gendering of the larger society from which they sprang. Before the nineteenth century, most scientists did much of their experimental or observational work alone or with an assistant, corresponded with others interested in the same areas of investigation on a one-to-one basis and met occasionally in the forum of the scientific society. In the fifteenth century under Henry IV of Portugal scientists were brought together in a laboratory-like setting, but this way of doing science was not adopted more widely until the start of the nineteenth century in universities and the start of the twentieth century in industrial firms. The popular image of the lone (and possibly mad) male scientist working late into the night in a grim laboratory – for example, Mary Shelley's *Frankenstein* – is now a fictitious one: very little science is now carried out by an individual or even a small team working alone. What has not changed significantly is the image of the scientist as male. This reflects the statistical reality that women are grossly under-represented in the sciences, especially the so-called 'hard' sciences like physics and chemistry.

Box 1.1.1 Scientific method

Experiments try to observe the relationship between two factors, one of which the experimenter can change to observe its effect on the other. The factor that can be changed is called the *independent variable*. The factor which is observed in order to see whether alterations in the independent variable change it is called the *dependent variable*.

Let's suppose we want to determine whether the temperature of the water has any effect on how well soaking removes fruit-juice stains in 100% cotton cloth. In this case, the *independent variable* is the water temperature: we can change this and observe its effect on the *dependent variable*: the degree of stain remaining (let's say) after soaking.

A variable can be either quantitative (something which can be expressed in numbers) or qualitative (something about which the observer makes a value judgement or something based on a relative comparison with another object). In our example, temperature can be measured on a standard scale (degrees Celsius), but the degree of stain remaining will probably be a qualitative variable. We could make the experiment more quantitative by using a light meter, say, to measure the darkness of the stain on white cloth.

The values of the independent variable are usually called *the experimental conditions*. The number of conditions depends on how many values of the independent variable the experimenter wants to test. In our example, suppose we wanted to test 10°C, 20°C, 30°C, 40°C, 50°C, 60°C, 70°C, 80°C, 90°C and 100°C, we would have 10 experimental conditions.

An experiment is described in terms of an *operational definition*. This lists the steps or operations that have to be carried out to observe or measure whatever it is that is being defined. In our example, assuming that we already have lots of cloth stained with a big stain, our steps might be: cut sufficient strips of cloth for testing all the experimental conditions (plus one which will not be soaked, the *control*), heat water to required temperature, submerge cloth for set time (we don't want the time to vary, or it becomes *another* independent variable and it will no longer be possible to tell whether the temperature, the length of time or a combination of the two is responsible for the degree of stain removal), remove cloth, dry it, observe the remaining stain by comparing it to the piece of the same cloth unsoaked, upon completing testing all 10 conditions, compare results.

We've already mentioned the *subject* of our experiment, though not by name, in the paragraph above. *Subject* is also the term for people or animals who undergo an experiment or who are observed. Jane Goodall's observations were of chimpanzees interacting in the wild; the chimpanzees were the *subjects* of her study. It is important in many types of experiments to make decisions about what kind of subjects to use. For example, in biological, medical or psychological experiments and observations it is usually impossible to make every individual a subject, so experimenters must choose subjects from among the set of all possible subjects. When this is done, we say we choose a *sample*. We have to have some basis for choosing. It may be *random* (a method whereby each individual in the whole of the population has an equal chance of being chosen). If subjects come from a 'captive audience', then the sample is not random and one cannot think of these subjects as forming a sample of any general population. Experimenters may make their own subjects – in our example the experimenter may soak a cotton cloth in raspberry juice to create a stain to test.

The change in the dependent variable produced by change in the independent variable is called the *experimental effect*. (However, there may be changes produced by variables other than the independent variable.) The experimenter has to design experiments to negate, to the greatest degree possible, these other variables or the effects of these other variables. It is the attempt to do this that makes science appear so reductionist – it is too difficult to deal with multiple independent variables (possible causes for the effect observed) so as many as possible of them are eliminated. The more control the experimenter has over the conditions of the experiments, the less likely it is that the experiments will be invalidated by the interfering effects from other variables. In our example, we want to be certain that time soaking is not such another variable, so we need a stop-watch to ensure that no one strip of cloth soaks any less or more than any other subject. We also want to draw the water from the same source, so that, for example, water hardness or softness does not vary.

The penultimate step is to evaluate results and publish. The evaluation often involves experimenters in subjecting the data they have gathered to statistical or other mathematical analyses. Publication must occur in a reputable, refereed journal (a refereed journal is one where the papers submitted are sent by the journal to independent experts for opinions as to the soundness of the work and whether or not the papers should be published by the journal in question).

A last step entirely outside the experimenter's control occurs when the experimenter's peers read the journal paper. They may put forward and publish criticisms of it, or try to duplicate the experiments in their own laboratories to determine the validity of the results. Because of subtle differences in techniques, materials and so forth, they may or may not obtain results consistent with those claimed, and publish in support or in criticism of the original paper.

In addition to absorbing ideas about science based on outdated or fictional representations, the media often misinterpret scientific findings. It is common to find that a relatively small research finding carefully reported in a scientific paper can end up appearing to promise, in the popular press, a cure for cancer when in fact the finding only points to a possible avenue of exploration for a better understanding of the mechanisms involved in just one form of the disease. This has the effect of leading the public to expect more of science than it can produce. Eventually, disillusion sets in and science is 'blamed' for its failure to produce the promised miracles (Florman, 1991).

PERCEPTIONS OF SCIENCE

It is inherent in scientific practice that scientists constantly argue about the nature and value of their work. Often this argument is limited in scope to which project gets the backing of the university department in seeking resources, but much wider-ranging and more fundamental arguments occur. Below I outline some of the perceptions and concerns that inform these arguments. However, it is important to note that these perceptions and concerns do not constitute mutually exclusive categories: any one person may hold overlapping or multiple views about science itself or even about individual scientific projects.

Science for knowledge's sake

This view holds that science is the seeking of knowledge for its own sake. It assumes knowledge is value-free and the search for it should remain unfettered.

> . . . if we make *good* things [as a result of scientific investigation], it is not only to the credit of science; it is also to the credit of the moral choice which led us to good work. Scientific knowledge is an enabling power to do either good or bad – but it does not carry instructions on how to use it.
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> *(Feynman, 1988, p. 241)*

Science and its ethics

An ethical argument can be made that scientific enquiry should not be free and unfettered because its potential application has an ethical dimension that must be determined beforehand. The direction that enquiry should take can be determined ahead of time for the greater good, which may be a social good or a religious good (science as a study of the universe undertaken to understand God's will) or a combination of both. Frequent ethical questions arise in medical research in particular: should enquiry be undertaken to determine cause and prevention as opposed to cure, and should less harmful and invasive means of treatment be explored and developed fully rather than accept the more drastic treatments? Who should be subjects of experiments, and under what conditions should experiments be conducted?

Big science and little science

A version of the ethical approach looks at the costs of scientific enquiry and the benefits which may derive. This cost–benefit analysis asks the question: can society afford a particular kind of science?

Some research results in direct benefits to human life: for example, the development of the germ theory of disease transmission provided a sound basis for arguments about the provision of clean water supplies and improved sanitation, which in turn resulted in diseases like cholera and dysentery becoming rare; the development of penicillin as a drug virtually eliminated amputations and deaths from septicaemia. Other areas of research are of doubtful or negative benefit (for example, weapons research). Still others are very expensive to undertake but do not result in any obvious benefit other than the extension of knowledge (for example, particle physics and astronomy). A cost–benefit approach assumes that we have limited resources of time, money and trained scientists and that we must make decisions about which projects to fund based on how much benefit can be achieved at what cost, and to whom.

Figure 1.1.1
Death (cholera) pumping water. The germ theory of disease transmission provided a sound basis for arguments about the provision of clean water supplies and improved sanitation.

Big science like astronomy is very costly.[2] So is research into drugs, where individual projects may provide great or little benefit, and the benefit may be primarily to a commercial organization which gets a return on its investment, or it may be of greater general benefit or both. Small science is inexpensive and may provide great or little benefit, depending on the project. Both big and little science may undertake projects of a similar nature: for example, research into drugs can be done on a large scale, as it is in the multinational drug companies, or on a small scale, for example in Nicaragua where the resource-poor health service undertakes research in herbal medicine to try to provide maximum health benefits to the population at as low a cost as possible. The hidden agenda for funding big science where little or no benefit accrues beyond the extension of knowledge is often that undertaking such research bestows prestige on the nation, the institutions and the individuals concerned.

The sociological view of science

Science can be influenced by struggles for personal, political, organizational and national power; this is especially clear when funding is in question or honour is to be bestowed. Langdon Winner (1991), speculating on modern science and technology states:

> Knowledge products, sometimes mistakenly called discoveries, are crafted within a complex, multi-centred social process . . . The credit lavished on the likes of Newton, Edison and Pasteur is better placed within the complex relations that link science and society in myriad patterns.

Another 'problem' in the conduct of science is its intensely competitive nature. While scientific teams co-operate among themselves, a team is in competition with others working in similar areas. The competition among scientists is more often for prestige than for money; however, prestige can guarantee the flow of funds to a research group. In addition, scientists may have an eye on whose name will go in the history books alongside important discoveries.

Watson and Crick, credited with the discovery of the DNA molecule for which they were jointly awarded a Nobel prize, failed to acknowledge their debt to Rosalind Franklin, whose painstaking work gave them considerable additional evidence. Watson, writing in 1968, belittled Franklin's contribution and indeed implied that she was 'difficult to work with' – he apparently did not like her cautious approach. Subsequently he added an afterword to his book, partly retracting his earlier position regarding her contribution. But his failure to credit Franklin fully grew out of both the 'great man' [sic] attitude to science and the fierce competition that prevails in much of science, where sharing credit amounts to diluting one's own contribution and lessens the likelihood of receiving a lion's share of funding and such prestigious recognition as the Nobel award.

Problems with method

Reductionism necessitated by the experimental method means that findings of experiments are often difficult to re-integrate into an understanding of more complex phenomena. The germ theory of disease, for example, makes it difficult to integrate observations that disease, even when it results from the presence of pathogens such as bacteria, often follows stress, or that changes in the environment may be responsible for changes in levels of certain types of disease (as in the example of bilharzia cited below).

It can be argued that method as currently defined in fact limits enquiry: peer review and the fear of negative peer reaction confines enquiry to 'acceptable' channels, ignoring possible valid lines of enquiry by designating them unacceptable. A science that uses all forms of ideas in its search for knowledge, rather than a science limited to acceptable 'scientific' ideas, could produce better results:

> There is no idea, however ancient and absurd, that is not capable of improving our knowledge. The whole history of thought [could be] absorbed into science and . . . used for improving every single theory. Nor [should] political influence [be] rejected. It may be needed to overcome the chauvinism of science that resists alternatives to the status quo.
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> *(Feyerabend, 1975, p. 47)*

A problem here is that the earliest hypothesis to be published which adequately explains the phenomenon observed becomes the 'working' hypothesis, no matter how many other hypotheses that can fully explain the phenomenon follow it. The first hypothesis must be *disproved* before it loses its primary position.

Further, there are subtle, unconscious influences on scientific methods:

> Science bears the imprint of its makers; the empirical and conceptual constraints familiar to objectivists underdetermine virtually all scientific conclusions leaving considerable scope for the influence of such supposedly non-cognitive variables as gender ideology.
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> *(Harding, 1986)*

TECHNOLOGY: WHAT IS IT?

Technology is both older than science and has had a much greater influence on the daily lives of people. *Tekhne* means art (in the sense of 'way of doing') and *logike* means reasoning – therefore reasoning about the art of doing. Technology is about coping with needs for food, shelter, health, communication and so forth in a practical way, by reasoning about available or possible materials and by using that reasoning to design and make practical objects, including tools used to make new materials, objects and tools. Many of these basic concerns for food, shelter, health and communication are, at the most fundamental level, domestic and therefore commonly fall into the sphere of women's work. Technology encompasses everything from the simplest stone, wood and bone tools and the modification of animal skins for purposes of clothing to automobiles, trains, systems for delivery of power, water and sanitation to homes, television, computers, the telephone system, textiles, cosmetics and modern weaponry.

Technology was frequently appropriated from the Third World by the West. The British, for example, considered Indian steel to be the best in the world in the 1790s and expropriated their techniques, making improvements on them. The result of this appropriation and improvement (and particularly of mechanization) is that indigenous industries become less economically competitive, wither and eventually die. The 'colony' comes to depend on the 'imperial' centre (Levidow, 1988). As less economically viable activities wither and die, the colony becomes a net importer of cheap manufactured goods and in turn supplies raw materials, cash crops and cheap labour.

How is technology different from science? Doing rather than discovering

Technology differs from science in that science is about discovering and explaining and technology is about designing and making. So technology encompasses design and method, though modern technology borrows heavily for its knowledge base from modern science. Science, for example, may investigate the properties of steel and plastics and build a body of knowledge about these materials whereas technology uses that knowledge, plus practical knowledge acquired in practice, to mould steel and plastic to practical ends like providing strong joists for buildings or tools for the kitchen.

MODELS OF TECHNOLOGY

Long and Dowell (1989) describe three models of technology which are generally applicable to understanding what technology is and how it works. Like all such models, there are no hard and fast boundaries between one model and another, and examples can be found which show instances where the models are combined.

The craft model

The craft model of technology most closely characterizes the older technologies such as potting, hand-weaving, wood-working, cookery and so on; it is the 'master–apprentice model' of technology. It makes use of practical rules of thumb, develops with experience, is specific and cannot be easily generalized. It is not often written down, though. For example, these days it is more common to see cookery books which include recipes with lists of ingredients and notes on method, but older cookery books were memory aids, merely listing ingredients; they often assumed that their readers knew a great deal about method and included only the sketchiest of notes. It is much more common nowadays to find manuals for all sorts of craft work, though most acknowledge that they are not substitutes for direct teaching by an expert and practical experience with materials. The craft model characterizes the technology of early periods and the early industrial revolution and technology in many Third World countries.

The engineering model

The engineering model of technology began to emerge in the late Middle Ages. It seeks to apply the practice of hypothesizing (asking 'what if' type questions) and testing to develop the practice of technology. Technology developed with this model is somewhat generalizable and forms a slowly changing body of practical, tested knowledge normally enshrined in writing. This model of technology characterizes nineteenth-century engineering and is still commonly applied today, particularly in established areas like civil engineering (and its concommitant art, architecture) and mechanical engineering. This model has, in the past, excluded women, who are only now gaining some entry as a result of changes in education and training. Past exclusion was either an unconscious result of attitudes about male aptitude for certain tasks or was a matter of explicit policy.

The applied science model

The applied science model of technology applies both prescriptive scientific knowledge and the scientific method to the solution of technological problems. This model characterizes twentieth-century, 'high' technological development, especially in areas such as electrical and electronic engineering, materials science and the systems approach to complex products. It is this form of technology which is most likely to seek to change nature to fit perceived needs. For example, this model of technology applies to the situation where scientific knowledge and experimentation is applied to, say, steel, to force the material into new forms that transcend its normal properties, making it available for new uses. This model tends to have excluded women less than the previous two because the rise of the fully professional technologist has very roughly coincided with women's battles to gain access to universities and the professions for which a university education is the ticket of entry.

Low, high, intermediate and alternative technologies

Low technology can best be defined as the most basic technologies of food production and preparation, shelter-building and body-sheltering (such as simple textiles), health maintenance and communication. These needs tend to be ranked in importance so that

food production and preparation and shelter-building and body-sheltering are more immediately important than, say, communication.

High technology is what is usually meant in the West by the term *technology*. High technology encompasses large *systems* for the production of food, the building of shelter and communication, and far more than basic needs are met. (In fact, many needs must be artificially stimulated, as present-day high technology in the West depends upon high demand to achieve economies of scale for production.)

Intermediate technology (sometimes called *appropriate technology*) is a concept which has grown out of attempts to apply technological solutions to problems of underdevelopment in many parts of the world. It was observed that high technology solutions failed partly or wholly to alleviate hunger, poverty and poor health. In many cases, high technology solutions have created more problems than they have solved. Large hydroelectric dams have, for example, created considerable social upheaval, taken land out of agricultural production, had unforeseen environmental impacts and greatly increased the incidence of certain water-borne diseases like bilharzia. This is caused by a parasite which at an intermediate stage in its life-cycle parasitizes a snail found in sluggish or still waters. Dams decrease the flow of water and encourage the spread of the snail which, while acting as a host to the parasite, spreads the disease to humans who wade, bare-footed or -legged, into the water. Bilharzia is not a problem in areas where water flows freely. The main benefit of the dams – the electricity produced – has not improved the lot of local people, who have little need for it and often cannot afford it.

Westerners and their institutions assumed the superiority of a technological way of life and based their models of development on it. However, to modernize along either Western capitalist or Soviet lines would be disastrous in ecological terms, and probably social terms as well. Intermediate technology seeks to *build* on low technology, local materials and local interest and knowledge by applying a more scientific approach to the development of tools and artefacts. Such technologies 'have often proved better suited to the actual needs and socioeconomic conditions in developing areas than programmes oriented to large-scale, capital-intensive projects' (Adas, 1990). An example of the application of appropriate technology is described by Bina Agarwal in Article 4.2, which describes the development of a more efficient wood-stove for cooking. Such technology often contributes significantly to easing women's work. The improved stove, for instance, greatly reduces the amount of fuelwood needed, and women do most of the fuel-gathering, often over great distances.

Alternative technology is also a more recent concept and is closely allied to the aims of intermediate technology. Alternative technology seeks to minimize the environmental impact of technology by seeking less destructive or resource-hungry ways of doing the same things or nearly the same things that high technology does. For example, the use of solar heating in houses to minimize the consumption of fossil fuels or the use of nuclear-generated electrical power reduces the impact on the environment of home heating. The materials used for solar heating (glass, metal, heat-holding paints) and the methods for determining how to achieve the best placement and use of the heating panels may very well draw on high technology. Calculating the best angle and placement of solar panels is a mathematically exacting exercise. The objective of an alternative technology like solar heating remains the same as that of high technology: to provide a significant measure of comfort (with some health benefits) to human life. Women have a considerable interest, and often an involvement, in alternative technologies. The Women's Environmental Network, described in Article 4.5, is a particular example.

THE ENGINES OF TECHNOLOGY

The development of Western technology as we know it began about the middle of the eighteenth century. Since then, per capita income in the West has increased tenfold, the population of Europe has increased by a factor of five, infant mortality has declined very considerably and the average life-span has doubled.

According to Rosenberg and Birdzell (1990), this cannot be attributed entirely either to imperialism (they note that prosperous European countries like Switzerland and Norway never adopted imperialist policies) or to the possession of abundant natural resources. Rather, they attribute it to a fortunate conjunction of economic needs and economic climate, access to and the dissemination of information about superior technologies, and since the 1880s the input of scientific sources of information. Productive technology has to be shaped to meet local needs, and local people have to be able to understand, experiment with and evaluate it both technologically and economically. For example, Japan in the nineteenth century had little land or capital available but was rich in labour resources. The Japanese quickly adapted techniques from land- and capital-rich (but labour-poor) America or shifted to different technologies. They substituted labour for capital, bought machinery second-hand to preserve their capital and aimed to maintain their investment by careful maintenance and repair of their machinery. The decentralized economies of the West encouraged experimentation with technology as no one institution had a veto on any particular avenue of enquiry or development.

Both the Western and the major socialist economies and technologies have had a heavy dependence on the military; indeed, the military has been an enormous engine of technological development. In the West, in deference to voters' sensibilities about the uses of their tax monies, military technology has commonly provided 'spin-offs' for civilian consumption: nuclear technology can be viewed as a militarily important technology that can be made palatable because it can also produce electrical power; computers were developed firstly for the military and only entered the civilian sphere a decade later. Much research and development in computer technology continues to be funded by the US Department of Defense and the UK Ministry of Defence. Development of lightweight but very strong materials for military aircraft and vehicles may find their way onto the domestic market in improved bicycle frames.

While the military was and remains today a major engine of technological development, individual engineers, designers, applied scientists and technicians often work in the areas they do because they feel strongly that improved and new technologies help in bettering the human condition. As with scientists, their motives may be quite mixed: they may combine a sense of mastery and power over a technology, a sense of curiosity, feelings of altruism and even a sense of the aesthetics of the things they develop.

GENDERING TECHNOLOGY

Technology is, popularly, strongly gendered. Certain technologies – textiles, manual agriculture, food preparation and storage, 'female' medicine and midwifery – are very strongly associated with women while others – hunting, mechanized agriculture, transport, weapons – are equally strongly associated with men.

There is some anecdotal evidence that, even in modern engineering and computing, women bring a different perspective to the work to their male counterparts. Turkle (1984a) notes that boys bring interests to, and use methods for, computer programming that are different from the interests and methods of girls. She fears that attempts to help girls in schools may lead to a different form of gender bias in computing – that girls' interests and methods will be seen as inferior rather than merely different. Florman (1984) notes some informal studies revealing that female engineering students are three times more likely to be interested in literature and broader social issues than their male counterparts. In the Soviet Union, only 5 per cent of women in science and engineering endorsed the party line on the dissident scientist Andrei Sakharov when he was in exile, while 24 per cent of their male colleagues supported the party line, indicating that the women were more willing than men to maintain links with people who are 'out of favour' with the establishment.

Women as scientists and engineers

Three factors are important in an individual's career choices: ability or inclination, access to education and training, and the perceived opportunity to practise a particular career. Women have been excluded from science and engineering careers on all three counts. Most women have met the assumption that 'women are not good at maths'. In the United States, university entrance is based partly on success in the Scholastic Aptitude Tests and it has been observed for years that there is a sex difference in maths scores, with boys achieving an average 45 points (out of 600) more than girls. However, investigation into the reasons for this discrepancy showed that it was not a lack of ability in girls that accounted for lower scores, but the fact that they were very likely to have had a half a year less maths than their male counterparts. In the past, universities also practised subtle and not-so-subtle sex discrimination: not having sufficient residential places available for female applicants, closing certain courses off to them (sometimes with the excuse that chaperoning on field trips would be a problem!). Women are less likely than men to receive public and institutional support even where the women come from families with fewer resources than their male counterparts. Perceptions of opportunity for careers further discourage women from taking up science or engineering – women see few role-models in such areas.

Hornig (1984) argues that, though educationalists feel it is important to reach girls in secondary education to interest them in careers in science and engineering, it is the universities that educate scientists and 'act as gatekeepers to the professions'. According to Hornig, women *appear* to constitute a smaller number of scientists and engineers because they constitute a smaller proportion of these than they do of other fields. In the United States in 1982, for example, about *50,000* women held PhDs in science and engineering, compared with about 20,000 in the humanities. However, science and engineering are very large fields, while humanities departments in universities (who mainly employ women with humanities PhDs) are relatively very small. Thus women constitute a larger proportion of the humanities (over one-quarter) than they do the sciences and engineering (where they constitute about 12 per cent).

While the picture is changing slowly, Hornig comments that scientists are not noted for their objectivity and unbiased judgement where social observations and decisions are called for. Science and engineering remain predominantly male and the university departments are still run by the men who made or enforced discriminatory rules in the recent past.

A similar gender gap exists in jobs. Fewer women than men who pursue a scientific or engineering career are likely to end up as managers, while more women are likely to end up in the less well-paid and less secure support activities: acting as librarians, collecting data and writing reports. Women scientists and engineers argue that the personal and psychological costs of pursuing a career beset by curtailed opportunity, token status and discriminatory employment practices are so high that they find it difficult to function in their chosen field, or even at times to function at all. The male 'mould' imposed on science and engineering, particularly in such fields as high-energy physics, makes them especially alien to women. Traweek (1984) observed that the traits required for entry into the world of high-energy physics were especially masculine: 'aggressive individualism, haughty self-confidence and a sharp competitive edge'.

Harassment exists in all workplaces: a very senior environmental engineer found that men tried either to treat her as something of a joke or to 'father' her. One man, accompanying her at a particularly toxic site, expressed concern lest she jeopardize her childbearing potential. She pointed out, much to his embarrassment, that he was equally jeopardizing his potential to father children (Hynes, 1984).

CONCLUSION

I have in this article laid some foundations for the debates and issues taken up in the following articles and chapters. Science is not a single ideology: it is a relatively broad church admitting a variety of practices and objectives. While it is critical of itself in its own terms, only recently have both scientists and non-scientists begun to question the historical origins of knowledge, the Western 'scientific miracle', the sociological, political and personal influences on who does science, who gets funding, and how science is done. As with many institutions, science was, almost from its outset, a strongly gendered institution, though some women have always been able to undertake science usually because they were either rich, determined or related to a male scientist. The issue today is how to change this.

Technology is older than science and in many places exists without scientific input. It encompasses virtually everything that human beings make: from prepared, preserved and stored foodstuffs of the most basic kind to the most complex systems for transport and communication. Much of technology, particularly of the domestic variety, has always been in the purview of women, but strongly gendered notions of the relations a human being should have with a machine or tool have tended to exclude women from participation in modern, high technology. Technology can be carried out as a craft, as an engineering discipline or as applied science. Since a participant in technological design, at whatever level, has to be able

INVENTING
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to appreciate the technology and evaluate it, women may be excluded even from simple technologies that have enormous impact on their daily lives.

The articles that follow discuss how women and feminists are changed by science and technology or seek to change practice by challenging underlying, often unspoken, gender assumptions. Outright rejection of science is an extreme position based on Foucauldian analysis; feminist scientists and technologists seek to keep objectivity as the centre of science but to show how conscious and especially unconscious attitudes to gender *and* race distort science. Women are now finding an increasing interest in technology, particularly in appropriate (intermediate) and alternative technologies because they are either concerned to lighten their crushing labour burdens or to carry out the function of living without unduly degrading the environment.

Notes

1 The study of animal behaviour. Women like Jane Goodall and Dian Fossey have been pre-eminent in modern ethological studies.

2 Whether a particular science is costly or not may depend upon the type of project undertaken; while the Hubble Space Telescope is enormously expensive, valid astronomical observations continue to be made by unpaid amateurs using relatively inexpensive telescopes and cameras.