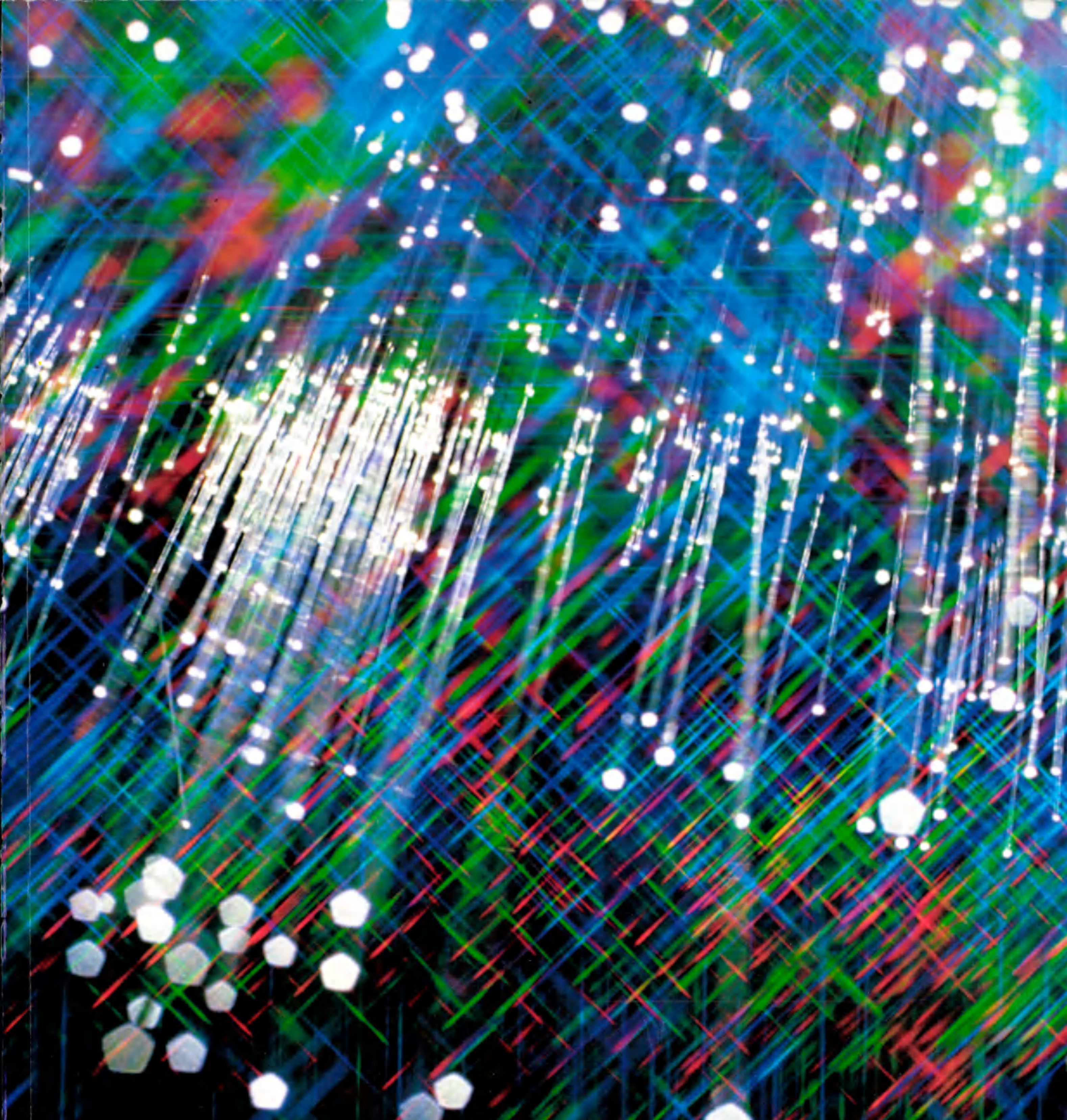

WORLD SCIENCE REPORT 1996

UNESCO

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Preface

FEDERICO MAYOR

The publication of this, the second *World Science Report*, coincides with a period in which we are celebrating the 50th anniversary of the establishment of UNESCO. It is a time for reflection and for taking stock – and for a re-affirmation of the Organization's mission in establishing peace through international cooperation in education, science and culture. We must pay tribute to the foresight of UNESCO's founders in deciding that science was indeed to have an important place in the programme of the Organization in the attainment of its goals of building peace, endogenous capacities and democracy. UNESCO's first Director-General, Julian Huxley, recognized the potential of science and technology for development in his first publication on the Organization in 1946. 'The application of scientific knowledge', he wrote, 'provides our chief means for raising the level of human welfare.' Whilst concepts like 'progress' and 'development' have succeeded one another in the decades that have followed, the Organization has not wavered in its belief in science as a major force in the development process.

And yet, paradoxically, although there is almost universal support for this idea of science as an engine of economic and social improvement, we have to come to the regrettable conclusion that the sharing of knowledge is extremely asymmetric and that in many parts of the world there is still a lack of political commitment to science. As the first part of this *Report* shows, there are scientific communities and infrastructures that fall far short of what must be thought of as a minimum viable level. As we prepare to cross that most symbolic of thresholds into the third millennium, perhaps this is the moment when political leaders should be asked to demonstrate their commitment to science. A realistic – and attainable – target would be for all countries of the world, especially the least developed, to devote a minimum of 0.4% of their gross national product to scientific research and development by the year 2000. Equally, as I have proposed on earlier occasions, Member States might consider devoting at least 3% of the assistance received from the United Nations Development Programme to science and technology.

Part One of the *Report* describes the state of science around the world. The overwhelming impression is one of change. The richest countries are needing to radically rethink their scientific and technological priorities and strategies in the face of economic constraints, saturated markets and new political – and ethical – challenges; states in the process of economic and social transition grapple with the delicate business of building new scientific infrastructures whilst retaining the desirable features of the old; and the developing countries are confronting the problems of providing the necessary critical mass in teaching and research essential for capacity-building and sustainable development. All, to one extent or other, are modifying their science according to changing conditions.

In the second part of the *Report* we examine a number of important issues confronting science and scientists today. It seemed unthinkable to produce a science report and not address the crucial issue of science ethics. In the same way how can we avoid the subject of international cooperation without which no large-scale science is possible today? Whilst the *Report*, like its predecessor, does not pretend to be encyclopaedic, we have nevertheless chosen to supplement the descriptive regional and national analyses with certain important environmental themes and the three major new technologies – biotechnology, information technology and materials science – which are examined in terms of their impact on society and their importance in national science and technology strategies.

The gender dimension of science has captured attention of late, and has appeared on the agendas of international fora and national governments. The UN Fourth World Conference on Women held in Beijing in September 1995 presented an important opportunity for stocktaking. Part Three of the *Report* examines the issue of gender and science and poses two key questions: 'science by whom?' and 'science for whom?'. The first addresses the obvious concerns over disparity of access to scientific education, careers and decision-making for women; the second examines the differential effect of science and technology on the lives of men and women, and looks at their respective needs and interests. Some of the reasons that cause governments and organizations to address gender disparities in science and technology are explored, and the role of international organizations, both governmental and non-governmental, is discussed. Women's empowerment – implying also women 'in power' (their current representation in decision-making positions and in parliaments amounting to only 5% and 10% respectively) – is essential for a significant modification of present trends.

If the *Report* has an overall message then it is that science and technology is an activity whose potential needs to be developed to the full to meet the global challenges of sustainable human development. This, in turn, calls for a better sharing of scientific knowledge, across societies and between nations, and a sustained commitment to science on the part of society as a whole – including ordinary citizens as well as politicians and scientists themselves.

Federico Mayor
Director-General of UNESCO

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Introductory essay: The case for scientific literacy

FRANCISCO J. AYALA

The Copernican Revolution is credited with changing man's perception of himself and his place in the universe. The Earth was no longer thought to be the centre of the world, as the ancients believed, but rather a small planet rotating around an average star.

The discoveries of Copernicus, Kepler, Galileo and Newton indeed showed that the universe was immense in space and time; that the motions of the planets around the Sun could be explained by simple laws, the same ones that accounted for the motion of physical objects on our Earth; and that the tides were caused by the gravitational pull of the Moon. These and other discoveries greatly expanded human knowledge, and yet the substance of the Copernican Revolution was embodied in something more fundamental than the accumulation of particular discoveries, however wondrous. Its great achievement was that it ushered in a conception of the universe as matter in motion governed by natural laws; the realization that the universe obeyed immanent laws that could account for natural phenomena. Therefore, physical phenomena could be reliably predicted and manipulated whenever the causes were adequately known. Science thereby came to be explanation by natural laws. The extensive knowledge we now have of the natural world is one outcome of the Copernican Revolution; the Industrial Revolution is another.

Science is a successful mode of inquiry, and also of problem solving. Science has thus brought about the stupendous technology that pervades the modern world: high-rise buildings; highways and long-span bridges; rockets that carry people to the Moon; telephones that provide instant communication across continents; computers that perform complex calculations in millionths of a second; agricultural crops with desired attributes; vaccines and drugs that keep bacterial parasites at bay; and gene therapies that replace DNA in defective cells. The accomplishments of technology may not all be an unmixed blessing, but science and technology have changed the world in which we live and will surely continue to do so in the future.

These statements lay the ground for the case I want to make: that scientific literacy, understood as an everyday working knowledge of science, is as necessary as reading and writing (literacy in the commonly understood sense) for a satisfactory way of life in the modern world. I wish to claim that scientific literacy is necessary for there to be a capable workforce, for the economic and healthy well-being of the social fabric and of every person, and for the exercise of participatory democracy.

SCIENTIFIC LITERACY

I should make clear at the outset that by 'scientific literacy' I do not mean detailed knowledge of scientific constructs, such as is conveyed in textbooks of physics, chemistry, physiology or genetics. I rather mean a comprehension of what might be called the scientific approach, or the scientific way of knowing, or even the scientific method. This comprehension requires that specific scientific knowledge be held, but this need not be ample or detailed, extensive through the disciplines or profound.

In this sense, a scientifically literate person would know that astrology is not science, and that children are not born with stronger muscles just because their parents exercise in the gym; but there is no expectation that a scientifically literate person would know the definition of angular momentum or that the expression of DNA is mediated by transfer-RNA molecules. To be scientifically literate implies that whether or not a person endorses a government programme for water fluoridation or for building a nuclear power plant is not a decision based on the prejudice that all tampering with natural resources is harmful (or, at the other extreme, unambiguously beneficial), nor on ignorance that decisions involve trade-offs, as may exist between a nuclear and a coal-fuelled power plant.

UNESCO has defined literacy as an individual's ability to 'read and write a short simple statement on his everyday life'.[1] With the phrase 'scientifically literate' I do not intend to mean that a person must be learned in matters of science, but I do not mean either that it suffices that a person be able to read and write. I rather mean something that has recently become known as 'functional literacy', defined as the ability to comprehend what is read or written to an extent sufficient to perform adequately in society, whether to communicate with individuals, to further one's own economic or other interests, or to participate in the democratic way of life.[2] Scientific literacy implies this functionality: the ability to respond to the technical issues that pervade our daily lives and the world of political action in a meaningful way.

THE NEED FOR SCIENTIFIC LITERACY

There is universal need for scientific literacy. I will support this claim with arguments derived from two increasing demands of modern nations. First is the need for a technically trained labour force. Second is the requirement that citizens at large pass judgment on the promises and actions of their governments and on the claims of advertisers of consumer goods.

President Bill Clinton of the USA has recently written that 'Technology – the engine of economic growth – creates jobs, builds new industries, and improves our standard of living. Science fuels technology's engine.'[3] This is not the place to argue that the cascade of causal agencies proposed by Clinton is correct: Science ⟶ Technology ⟶ Economic growth. I will, nevertheless, point out in support of that causation the strong correlation between the size of the investment that a nation makes in science and technology research and development (usually assessed as the fraction of the country's GDP invested in R&D) and the standard of living and other measures of economic well-being that predominate in that nation.

The point I wish to make is that the productive sector of the economy of any industrial nation demands a labour force that is scientifically literate.[4] Thus, a country's economic well-being depends on there being high levels of scientific and technical literacy. Scientific and engineering breakthroughs are at the basis of industrial productivity. But economic and industrial development more immediately come from the adaptation of scientific ideas: new manufacturing materials and processes, advances in productivity and performance of workers, quality control of products, and consumer appeal and marketing. Economic development certainly depends on the scientists and engineers who discover and invent and on those who develop these innovations. But the successful implementation of the innovations depends on there being cadres of educated workers, skilled in the management of machinery, computers, control centres, quantitative information and materials.

The workers required by modern industries have to understand technologically complex instructions in order to operate equipment and communicate and cooperate with each other in tasks that are far from purely repetitive. This need, as well as the benefits of scientific literacy, extends beyond industry to other sectors of economic activity such as agriculture. The greatly increased agricultural productivity of recent decades in countries such as the USA is largely

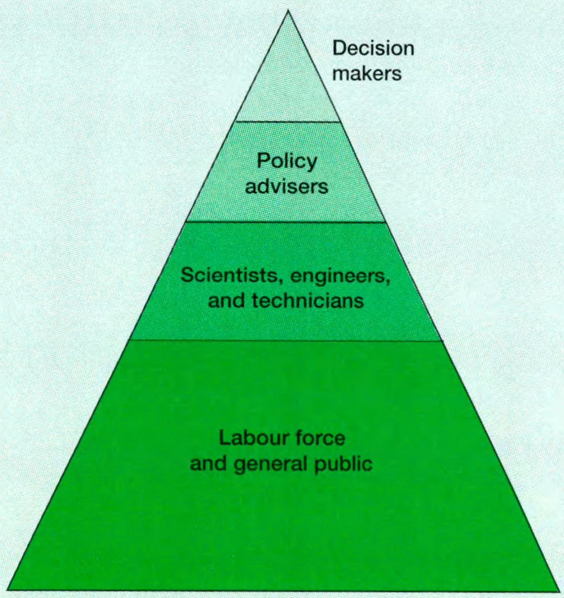
1. Cited by Graubard, S.R. (1983) on p. 232 of Nothing to fear, much to do, *Dædalus, Journal of the American Academy of Arts and Sciences*, 112(2): 231-48.
2. S.R. Graubard defines functional literacy as 'the capacity to read and write so as to be able to function effectively in the group or community to which the individual belong[s].' (See preceding note.)
3. Clinton, W.J. and Gore, A., Jr (1994) *Science in the National Interest* (Preface), Washington, DC: Executive Office of the President, Office of Science and Technology Policy.
4. The fraction of the labour force involved in 'knowledge industries', i.e. those that produce, process and distribute information goods and services, increased in the USA from about 5% in 1860 to about 50% in 1980. (Bell, D., The social framework of the information society, in Forester, T. (ed) (1981) *The Microelectronics Revolution*: 521, Cambridge, MA: MIT Press. Cited by Walberg, H.J. (1983) Scientific literacy and economic productivity, *Dædalus, Journal of the American Academy of Arts and Sciences*, 112(2): 1-28.)

attributable to the introduction and application of modern farming practices and the use of efficient machinery that requires skilled operators.

Scientific literacy is also required for informed public involvement in the political and public life of a nation. Information about technological and scientific matters is required for an increasingly large proportion of the decisions made at the highest levels of government. Whether or not a highway system will be developed, and where and how; how to decide between the development of fuel-fired, hydrologic or nuclear sources of energy; how to protect and improve the water supply and air quality; the exploitation of mineral or marine resources; the preservation and commercial use of forests, rivers and coasts: these are among the numerous political decisions that cannot wisely be made without scientific and technological knowledge. The decision makers need to rely on policy advisers who are scientifically and technologically qualified for adequately briefing government officials and others on these sorts of issues. But the decision makers themselves need to be scientifically literate in order to interpret, evaluate and use the experts' advice for making policy decisions and implementing them through the political process. Democratically elected legislators and government officials are the representatives of the people and must take responsibility for their decisions, rather than simply delegate them to the experts.

The participation of the body politic in the science and technology decision-making process may be represented by a pyramid (Figure 1). At the top are the government officials (executive, legislative, judiciary) in charge of making and executing political decisions; just below them are the policy advisers: experts who provide the policy makers with scientific and technological analysis of the issues, including their economic and public health consequences. The third level is represented by the scientists, engineers and technicians who embody the technological expertise of the body politic, who get the industrial

FIGURE 1
PARTICIPATION OF THE BODY POLITIC IN THE SCIENCE AND TECHNOLOGY DECISION-MAKING PROCESS



Source: derived from a representation proposed by Almond, G. (1950) *The American People and Foreign Policy*, New York: Harcourt Brace.

and technological engine started by introducing new inventions, developing technologies, improving manufacturing processes and the like.

At the base of the pyramid is the labour force, the large majority of those involved in the productive sector of the economy. They need to be scientifically literate in order to fulfil the needs of modern industry and commerce, as I have argued. From the perspective of political practice and the exercise of democratic freedoms and powers, it is apparent that the public at large must also be included in the large base of the scientific pyramid because all citizens are (or should be) involved in the election of government officials, who are selected on the basis of their performance or the promises of a political platform. Science and technology have commercial, strategic, bureaucratic and public health consequences not at their margins, but at the core of these essential components of the political process. A participatory democracy requires that the electorate – the public at large – be scientifically literate so that it may or not support the proposals or decisions of officials, and endorse or not their election based on some understanding of the implications of those proposals or decisions.

A participatory democracy will not be consummated if the import of the technical premises of political decisions with great economic consequence, and which affect the present and future welfare of a nation, can be understood only by a small fraction of the population. Citizens can and should be exposed to the arguments and counterarguments of contending experts. But a public that has no inkling of the technical issues at stake exposes the democratic process to exploitation by special interests and demagogues, and even to fraud (of the kind that fakes pseudoscience such as astrology or parapsychology in the cloak of science). The public need not be endowed with scientific knowledge of the kind that is imparted in science classes and textbooks, but it must be able at least to evaluate the cogency of the arguments advanced by experts and understand the economic, ecological or health consequences which might follow.

Policy making starts with educated guesses as to what the future may bring to the body politic as a consequence of the interventions of the government. A scientifically literate public will be prepared to evaluate current plans, promises or platforms in terms of previous trends and outcomes. Scientific literacy will often be sufficient to see through vacuous promises of cost-free social programmes, risk-free decisions affecting the environment or misleading advertisements for consumer goods. In the case of complex issues, the public should at least be able to assess the cogency of the analyses made by political commentators, social critics and the responsible media.

THE ROLE OF SCHOOLS

The goal of scientific literacy requires that meaningful science education be imparted in schools. The issue of science education in schools is too broad, complex and difficult to be explored here, but I wish to make three points briefly.

The first point is that science education should reach *all* students. If the argument I have sketched above is accepted, this follows. Science education in primary and secondary schools must fulfil several objectives. It must prepare the students who will go on to study science and engineering in technical schools, colleges and universities to become the scientists and engineers who occupy critical positions in the industrial and economic development of modern nations. (These are the individuals who make up the second tier of the science and technology pyramid.) Schools must also prepare the workforce demanded by science-based industries and by the increasingly numerous enterprises that also require technically skilled labour. Finally, schools must accomplish the goal of preparing people for participatory citizenship, which I have argued requires as a minimum some understanding of the nature of scientific knowledge for individuals to make personal decisions that affect their day-to-day living as well as their participation in the body politic. These broad goals make it imperative that science education be started in the early school grades and continued through all years of mandatory education.

In virtually every nation there is dissatisfaction with the scientific education imparted in schools. This observation brings me to a second point. Science in schools is largely taught as a reading subject, something that is learned from a textbook and is later regurgitated at examination time. There seems to be abundant evidence, however, that science is much better learned (and that students are more likely to develop an interest in learning it) when it is taught by hands-on methods, by illustrating principles with practical observations and experiments, which through elementary and much of secondary school may simply derive from the daily experience of the students.[5]

The last point I wish to make concerns science education in nations where general literacy is low, or in villages and remote areas, or where the years of schooling are few and little, if any, scientific equipment is available for instruction. There are many opportunities for measuring, counting and classifying in a classroom and in the immediate surroundings (the students themselves and classroom objects can serve many purposes). The relationship between form and number can be taught by engaging the children in sewing, weaving, carpentry, bookkeeping and mapping. Similarly heat and light, sound and motion can be used for teaching physical science. The experiences of growing up and childbirth within the family, the growth of plants and animals, the physiological consequences of the seasons, and much else in the immediate experience of the child will serve to teach biology. The general point I am making is not only that high-quality science education through elementary and much of secondary school does not require technical equipment, but also that it will be much more successful by relying on the daily experience of students.

The success of science and mathematics teaching will, of course, be largely predicated on the preparation and dedication of the teachers of primary and secondary schools – a subject that goes beyond my objectives here.

I will conclude by making the point that science education need not end with the school years, either for those who become scientists and engineers, or for the general population. The media can educate as they report and comment on political, economic and health news with technological import, but also as they entertain. Television, in particular, is a powerful agent for continuing the public's science education. Commercial interests now handicap this opportunity, but this is because news reporters and producers of topical programmes fail to convey the seductive excitement of discovery and technological knowledge. The time is ripe for the press, radio and television to do their share in achieving scientific literacy, as they fulfil their other unique but essential functions in modern society.

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Professor Ayala has held senior positions in a number of other professional societies and served as a member of various national advisory bodies. He is a frequent lecturer in universities and institutions in the USA and elsewhere, and has more than 500 articles and 10 books to his credit.

5. The literature on science education in schools is very extensive. One notable example that may be mentioned is the long-term Project 2061 of the American Association for the Advancement of Science. This three-phase plan was initiated in 1986 for the purpose of improving school education in science, mathematics and technology. Phase I, completed in 1988, focused on the substance of scientific literacy and resulted in several documents, of which the most important is *Science for All Americans* (1988, Washington, DC: American Association for the Advancement of Science). Phase II has involved teams of educators and scientists transforming the substance of *Science for All Americans* into alternative curriculum models for use under different economic, cultural and social conditions. An important outcome of Phase II is *Benchmarks for Science Literacy* (1993, New York: Oxford University Press). Phase III is intended as a widespread collaborative effort that will continue for a decade or longer and will involve many groups seeking to use the resources of Phases I and II towards the goal of achieving scientific literacy through school education.

1

STATUS OF WORLD SCIENCE

Science and technology systems: a global overview

PIERRE PAPON AND RÉMI BARRÉ

In all civilizations people have felt the need to know and understand the world and society in which they live, and have gradually found it necessary to organize the activity of obtaining new kinds of knowledge. This is the background to the emergence of scientific research, whose aim is to measure and devise experiments and theoretical models so as to be able to understand and interpret natural phenomena, discern the structure of matter and living organisms, and so on. At the same time, the development of new technologies has become an essential feature of industrial societies and, since the second half of the 19th century, has been closely linked with scientific research.

No civilization has ever monopolized scientific research and technological development in the long term. Both science and technology are the result of history: the leading role now played by science and technology is the result of a lengthy evolutionary process which has gradually given rise to the emergence of 'modern science' and the technical know-how on which technology is based. Each civilization has given its stamp to scientific institutions which enabled scientific and technological activity to be pursued in more or less close symbiosis with the way society is organized, with its culture and its political structures. Long before any European state, China and the Islamic countries managed to give a relatively organized and developed form to scientific activity and were responsible for major discoveries in the fields of magnetism, acoustics and optics. Many large cities in the Islamic world had an astronomical observatory at a very early date, and the observatories of Baghdad, Cairo and Samarkand played a major role in the development of astronomy from the 9th century onwards. In the Islamic countries the education system played an important role in the dissemination of knowledge, with universities like the al-Azhar University in Cairo leading the way in this field. Likewise in China the imperial state set up an extensive administrative system within which the production of scientific and technological knowledge had an important place. By way of example, astronomy was regarded to some extent as an official science since China was an agrarian country and astronomers were employed in the drawing up of official calendars. The same was true for mathematics, physics and, above all, hydraulics. Most societies have sought, at a very early stage, to establish a stable and viable long-term structure for the systematic and organized production of scientific and technological knowledge, a process that we now call research and development.

However, it was in Western Europe in the 16th century that science began to develop a stable institutional structure and declared its independence from philosophy and theology. During the same period the expansion of international trade with the great maritime discoveries favoured the emergence in Europe of a class of merchants who were keen to use the new technological inventions. At that time and for a long time to come, the work of learned individuals (yet to be called 'scientific research') was restricted to academies or the teaching chairs at universities and colleges. The first scientific institution in modern history in the West was the *Accademia dei Lincei*, founded in Rome in 1609, of which Galileo was a member. The academies of science of London and Paris, founded respectively in 1660 and 1666, were real institutional innovations: their purpose was to replace purely philosophical speculation by observation and experiment. They also instituted a new form of relationship between the world of knowledge and the political authorities, which gave social 'status' and political recognition to the production of knowledge and, consequently, to research.

This institutionalization of scientific research was continued and consolidated, particularly from the 19th century onwards. Scientists, far-seeing university administrators and clear-headed politicians in Europe became aware that the development of knowledge could no longer be the affair of isolated, albeit brilliant individuals. Research required major resources:

laboratories with apparatus and teachers assisted by teams of students, research workers and technicians. The establishment in 1911 of the Kaiser-Wilhelm Research Society (now the Max-Planck Society for the Advancement of Science, with headquarters in Munich) marked a real turning-point: for the first time a state had created a research institute outside the university system.

Many European countries were to follow this example after the First World War, in particular France, which established the *Centre national de la recherche scientifique* (CNRS) in 1939, and China with its Academy of Sciences. During the same period industry was establishing its own research laboratories; scientific inventions were the source of technological innovations, particularly in the field of organic chemistry.

Nowadays, science and technology (S&T) are basic components of human activity. They largely determine the view that our societies take of the future and they enable states to meet economic, social and cultural demands. It is for that reason that the provision of backing for scientific research to generate new understanding and stimulate technological innovation is now an integral part of public policy, along with S&T's economic, social and military components and corporate strategies in industry. Setting up research programmes; making the best use of publicly funded research and applying the results in different fields; stimulating innovation in and strategy for industrial research; meeting social requirements; organizing international cooperation programmes; and training specialists – all these activities require a wealth of protagonists and institutions to take the necessary decisions. Together they form a genuine S&T 'system' with both national and international components. National research and technology policies, and those of major industrial groups, are designed to keep this system not only alive but evolving. At the national level it is mainly the job of ministries responsible for research to update the objectives and make the choices and decisions necessary as part of the strategy behind our collective aims and ambitions.

THE MAIN AIMS OF RESEARCH AND TECHNOLOGY

Scientific research, like most of the work involved in technological development today, means mobilizing the skills of a wide range of professionals, from university scholars and scientists to engineers and technicians. The purpose of their work and therefore the functions carried out by the professionals involved are, of course, highly varied. Broadly speaking, they can be broken down into five main categories, as follows.

Production of basic S&T knowledge

This is the main purpose of basic or fundamental research, the objectives of which are set for the long term. Results are published in articles in scientific journals (if every discipline is included, more than 75 000 titles of specialized periodicals have been recorded) or disseminated at meetings and conferences. This type of activity also provides the input to databases.

Training

In most university systems, teachers are also involved in research work. This provides some guarantee of quality in higher education, as well as being instructive for the students, in particular for those doing, or about to do, postgraduate work. It should be emphasized that in many countries today, this training is also carried out by scientists and research engineers from both public and private laboratories and, increasingly, by international cooperative programmes.

Production of knowledge and technical expertise required for public policy

A great deal of government work consists of defining technical standards and regulations by means of various types of procedures that could be described as 'the daily practice of scientific expertise and technological evaluation'. This includes the operations of control commissions for new chemical and pharmaceutical products, the evaluation of industrial and technological risks, and the monitoring of water quality. All this is based on the expertise of scientists who for the most part work for public establishments. The environment, public health and the food industry are all examples of sectors where technical expertise is playing an increasingly important role in our society, involving appraisal, diagnostics, situation analysis reports and technical questions of all sorts (such as the state of the environment, the safety of an industrial facility, and so on). In many countries research bodies are required both to promote research in their field of competence and to place their expert knowledge at the service of the state. The development of high-level S&T research enables the state to obtain the expert advice it needs to discharge its responsibilities.

Contribution to national strategic programmes

Modern states very often have 'strategic' objectives, in the broad sense of the word, denoting key national priorities. These are most often part of their power logic: they require complex weapons systems that do not depend on foreign nations' know-how, need satellites to ensure control over their own telecommunications and wish to be energy independent. To meet these objectives they have to set up large-scale technological research and development (R&D) programmes within their main public research organizations covering areas such as nuclear or aerospace research. These programmes are also implemented, in industrialized countries at least, in the laboratories of industrial corporations (in the public or private sectors) in fields such as electronics or aeronautics. The results of this work generally remain unpublished, and form the basis of international competition which does not follow free-market principles. This concept of strategic planning has recently been extended to key industrial sectors such as telecommunications and certain manufacturing technologies such as robotics.

Participation in industrial innovation

The so-called R&D phase takes place upstream of innovation, that is, before the first use or commercialization of goods or services. Scientists and research engineers, particularly in industrial corporations, are therefore involved in a process which results in the development of new products and processes to be industrialized and marketed. Research work, generally applied in nature, often obeys economic rules based on stimulating corporate innovation. It should be noted, however, that not every innovation is the result of research work. Design and engineering offices, manufacturing departments, heavy industry and the service industries are also sources of innovation (software systems are increasingly innovations in themselves, for example).

One might say, by analogy with scientific research, that the patent is the basic product of technological activity. It is an intangible asset, like a scientific publication, but it gives its holder a monopoly and has market value, which a scientific publication does not. The patent recognizes an invention, such as an industrial process, or a new product or material. In all fields of technology in 1991, 81 000 patents were granted in the USA to inventors of all nationalities (as against 62 000 in 1986) and 41 000 patents in Europe (directly registered through European channels).

Technological innovation is also integrated into the capital goods and components of various types that a company develops or uses for production purposes. For example a car industry assembly line may use various computers to control the robots involved in the manufacturing process. Innovation is therefore the product of highly diverse processes.

All these S&T activities, some of which, as we have seen, date from many centuries ago, were embodied within a concept which gradually emerged at the start of the 1960s, that of R&D. Work by the Organisation for Economic Co-operation and Development (OECD) on the statistics of research expenditure has played a major role in the agreement by experts upon a common typology that over the last 30 years has come to be known as the *Frascati Manual*, in which three categories of R&D work are defined.

Basic or fundamental research covers all the experimental and theoretical work undertaken to acquire basic knowledge on observable phenomena and events, without the scientists having any *a priori* prospective applications for their work. Major names in science such as Max Planck, Marie Curie, Vantaka Raman and Jacques Monod worked with this state of mind, and they may be appropriately deemed 'fundamentalists'.

Applied research, on the other hand, corresponds to innovative work whose purpose is to acquire new knowledge for practical application (industrial, for example). The work by Louis Pasteur in the 19th century on fermentation or silkworm disease was applied research, even though some of the discoveries he made in the process were 'fundamental' in nature.

There remains a third category of research work: *experimental development*. This involves systematic work based on existing knowledge obtained via research work or practical experimentation in order to manufacture new products or develop new industrial processes. For example, the discovery of new polymers by research laboratories gave rise to the manufacture of plastics, but transfer to the industrial phase was only possible after investment in further development work, requiring the setting up of pilot plants for testing and adjusting.

We can thus see how basic research, applied research and development are linked within our typology of S&T (our five categories). While the border between basic and applied research is often hazy, it is clear none the less that in almost all national S&T systems it is basically the commercial companies and certain state technological organizations (civilian and military nuclear power stations, or petroleum research institutes for instance) that carry out development work, either linked to the target of stimulating industrial innovation or in close liaison with strategic state programmes. Basic research is very often linked to training, while applied research is to be found as often in institutions producing the knowledge and technical expertise required for public policy as in those involved in the development of strategic state programmes, and of course in industrial research laboratories.

As with any other form of classification, the *Frascati Manual* lends itself to criticism. Why, one might ask, do we need a taxonomy of S&T activities on which everyone agrees? Classification, however, is not just the obsession of statisticians or R&D administrators. Its motivation lies in the desire of political and administrative authorities and captains of industry in every country around the world to have solid grounds for strategic decisions. The budgetary constraints of recent years and the need to reorient programmes in order to take account of new priorities have made this even more desirable.

Furthermore, while the notion of development is more or less clear when referring to industrial activities, it is worth observing that it is much hazier when applied to military matters (such as the development of new weapons). The defence ministries of the main industrial countries (including the USA, the UK, France and Russia) classify under this heading prototype test work (of military aeroplanes for example) which, in general, is extremely expensive. One has to be prudent, therefore, when analysing national R&D strategies, since for some countries this entails accounting for the fact that the concept of development has been expanded to cover certain work for military purposes.

Similarly, the dichotomy between basic and applied research is not always relevant, either from the scientific point of view or from that of economics. Is research on the role of carbon dioxide and other chemical substances in the 'greenhouse effect' basic or applied? The distinction, it has to be said, is sometimes specious. In certain industrialized or developing countries where the public research sector is very large, we are led to distinguish between public R&D expenditure allocated to basic (or fundamental) research on the one hand, and that allotted to research programmes of collective interest on the other. In areas such as public health, the environment, energy, telecommunications and transport, public research organizations perform basic and applied research which is directly linked to public assignments in the broad sense of the term, such as enhancing the health of our fellow citizens, understanding environmental evolution, and so on. Since a great deal of their work is therefore 'finalized', we may consider their research to be equally finalized, and aiming to meet a social requirement. In Anglo-Saxon R&D terminology, this type of research is referred to as being 'mission-oriented'. It is, in a way, finalized research work on the borderline between basic and applied research. In this category we may classify a large part of research in the biomedical sciences (for example that on the HIV virus or on tropical diseases), in such areas as the environment, energy control, the engineering sciences and basic technological research in data processing and robotics. This work is carried out in research institutes, councils and agencies in the public sector in conjunction with the public authorities or major public services and is therefore linked to national public policy.

INDICATORS

Science and technology indicators are quantitative units of measurement of the parameters defining the status and dynamics of research and technology systems. Possible uses for these indicators are highly diversified: as a national overview for science policy makers or legislative authorities, strategic analyses for decision taking by research institutions, S&T surveys or programme evaluation, and so on. An increasing number of leaders in S&T are confronted with decisions and choices which have to be based on such indicators.

Three types of indicator are used in this global overview which make international or interregional comparison possible.

Resources dedicated to S&T activities

The measurement of resources is made at the level of each country by national surveys on R&D expenditure and scientific staff.

Measurement of scientific production by publications

Scientific activity is measured by its production of scientific publications (science bibliometry). A publication is indeed a basic product of scientific work but, as we have seen, it is not the only one: science also generates other forms of 'product', for example higher education or technical expertise. The indicator focuses here on just one specific aspect of scientific research.

Indicators have been calculated using the databases of the *Science Citation Index (SCI)* and *Compumath* established by the Institute for Scientific Information (ISI), based in Philadelphia, USA. The 3 500 or more science journals whose publications are indexed in the ISI databases are classified into eight disciplines.

Measurement of technological production by patents

Technological activity is measured by patent production (patent bibliometry), which indicates the level of inventiveness and creativity in technology for industrial purposes.

These indicators were used, and more fully defined, in the *World Science Report 1993*. Despite their imperfections, they are the most widely accepted means of measuring and comparing S&T activities in the world. Some of their limitations are discussed briefly below.

For *resource indicators*, the difficulties stem on the one hand from the definition of what is a research activity and what is a researcher, which can vary considerably from one country to another, and on the other hand, from the absence of reliable exchange rates in 'purchasing power parity' for many countries, which means uncertainty in the conversion to a single

TABLE 1

GROSS DOMESTIC EXPENDITURE ON RESEARCH AND DEVELOPMENT (GERD), GROSS DOMESTIC PRODUCT (GDP) AND GERD/GDP RATIOS FOR DIFFERENT AREAS IN THE WORLD, 1992

	GERD[1,2]	GDP[1]	GERD/GDP (%)
European Union[3,6]	117.67	6 079	1.9
European Free Trade Association[3,7]	5.47	233	2.3
Central and Eastern European Countries[4,8]	2.89	188	1.5
Israel[4]	1.24	64	1.9
Commonwealth of Independent States[4,9]	4.13	496	0.9
USA[3]	167.01	5 953	2.8
Canada[3]	8.13	537	1.5
Latin America[5]	3.93	1 063	0.4
North Africa[5]	0.72	160	0.4
Middle and Near East[5,10]	3.11	598	0.5
Sub-Saharan Africa[5]	1.09	245	0.4
Japan[3]	68.31	2 437	2.8
NICs[4,11]	10.73	824	1.3
China[4]	22.24	3 155	0.7
India[4]	7.10	940	0.8
Other countries in Far East[5]	0.69	982	0.1
Australia and New Zealand[3]	4.12	341	1.2
World total	**428.58**	**24 295**	**1.8**

Note: For non-OECD countries, both the correspondence between national currencies and US dollars and the definition of what is included in 'R&D activities' raise many difficulties. The figures presented can only be considered as orders of magnitude. The recent estimates of GERD by the University of Cambridge and published in the *European Report on S&T Indicators* suggest much higher figures than previously considered for China and India, due to the value of the purchasing power parity exhange rate; the opposite is true for the CIS countries.

1. The monetary unit is US$1 billion (current), calculated in purchasing power parity (PPP), except for the countries marked with 5.
2. Gross domestic expenditure on R&D (GERD) measures the spending on all R&D activities in the national territory, all sources of finance combined, including those from overseas.
3. Data from the OECD.
4. Data from the *European Report on S&T Indicators*.
5. Values in US$ billion calculated from the exchange rate of the national currencies; data from UNESCO, plus OST estimates.
6. EU: the 15 member countries of the Union as of 1995: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden and the UK.
7. EFTA: the four member countries as of 1995: Iceland, Lichtenstein, Norway and Switzerland.
8. CEEC: includes Baltic States (Estonia, Latvia and Lithuania) but excludes former Yugoslavia.
9. CIS: republics of the former USSR but excluding Baltic States.
10. From Turkey to Pakistan.
11. Newly industrialized countries or economies of Asia (Republic of Korea, Malaysia, Hong Kong, Singapore and Chinese Taipei).

Sources: OECD (for OECD countries); European Commission (1994) *European Report on Science and Technology Indicators*, Luxembourg: Office for Official Publications of the European Communities (for the other countries for which GDP and GERD are presented at purchasing power parity rate); UNESCO (for the countries for which GDP and GERD are presented at the exchange rate of the national currencies). Adjustments and estimates for incomplete data from OST, 1995.

currency for international comparison. Another point is that resource indicators make little or no distinction between the disciplines of science and technology.

TABLE 2
R&D SCIENTISTS AND ENGINEERS AND POPULATION RATIOS FOR DIFFERENT AREAS OF THE WORLD, 1992

	R&D scientists and engineers ('000s)	Population (millions)	R&D scientists per thousand population
European Union	740.9	369.0	2.0
European Free Trade Association	32.6	11.9	2.7
Central and Eastern European Countries	285.5	131.0	2.2
Israel	20.1	5.4	3.8
Commonwealth of Independent States	452.8	283.0	1.6
USA	949.3	257.5	3.7
Canada	64.6	27.8	2.3
Latin America	158.5	464.6	0.3
North Africa	81.6	219.7	0.4
Middle and Near East	117.4	465.9	0.3
Sub-Saharan Africa	176.8	482.6	0.4
Japan	511.4	124.8	4.1
NICs	136.7	92.5	1.5
China	391.1	1 205.0	0.3
India	106.0	887.7	0.1
Other countries in Far East	60.3	513.5	0.1
Australia and New Zealand	48.5	21.2	2.3
World total	**4 334.1**	**5 563.1**	**0.8**

See Table 1 for definitions, sources and notes.

Note: The figures for China and India are largely under-estimated and do not fit with the GERD values given in Table 1.

Sources: OECD; European Commission (1994) *European Report on Science and Technology Indicators;* UNESCO; OST estimates and treatment, 1995.

For *indicators of scientific production* (publications), the evaluation of possible bias consists of questioning the representativeness of the science journals used in the databases in question, in this case the *SCI* and *Compumath.* Whilst the criteria used for the selection of science journals in these databases are solid (to be chosen, for example, a journal must have an average number of citations received by the articles it publishes above a certain threshold), it is clear that the journals of industrialized countries published in the English language are over-represented.

This question has been the subject of numerous debates and raises a genuine problem for the diffusion of research carried out in developing countries. In effect, the scientists in these countries face the following dilemma: publish the results of their work in national journals, which are neither distributed worldwide nor indexed in major databases; or seek acceptance in the more prestigious international periodicals, thus depriving the national journal of their contribution. By the same token, the publishers of the national reviews complain of the difficulty in being accepted by the influential databases.

These problems are being examined by a number of international and national organizations in order to find a solution that would enhance the diffusion of scientific research results from the developing countries, improve the quality and regularity of national journals and favour the setting up of regional databases.

For *indicators of technology production* as measured by patents, the evaluation does not concern the databases (they are exhaustive and exact), but the interpretation that can be made of the indicators.

A first possible bias may stem from the fact that firms may have various strategies regarding patenting, resulting in differing numbers of patents for a similar capability. However, the present figures are derived from counts on all patents and all firms, which tends to compensate for such micro-biases. A second possible source of bias is linked to the fact that the firms of a certain territory or country tend to patent more there, since they relate closely to their domestic market. To overcome this problem the indicators are computed on patents taken out in the two major open markets, namely the USA and Europe. Nevertheless, those countries which do not aim at exporting to the USA or Europe will still tend to be underrepresented.

Thus, it is important to remember that each indicator merely represents one facet of reality (and even then only partially): resource indicators say nothing about results; scientific publication indicators say nothing about work in training or technical expertise; and patent indicators say nothing about technological fields in which no patents are granted, nor do they say anything about the use of the patent for innovation. It is clear that indicators only have meaning when considered together, since it is obvious there can be no single unit of measurement for so complex a system.

Despite all their limitations, current indicators may be considered to give correct scales of magnitude for the parameters they measure and, when considered as a whole, to give a fairly reliable representation of reality.

TABLE 3
SCIENTIFIC PRODUCTION, MEASURED BY PUBLICATIONS, 1993

	World share 1993 (%)	1993 index (base 1982 = 100)
European Union	31.5	107
European Free Trade Association	1.7	100
Central and Eastern European Countries	2.3	87
Israel	1.0	90
Commonwealth of Independent States	4.8	56
USA	35.3	96
Canada	4.5	108
Latin America	1.5	127
North Africa	0.4	111
Middle and Near East	0.6	186
Sub-Saharan Africa	0.8	89
Japan	8.1	119
NICs	1.4	412
China	1.2	347
India	2.1	83
Other countries in Far East	0.1	113
Australia and New Zealand	2.7	94
World total	**100.0**	

For definitions of the regions of the world, see Table 1.

Note: Scientific production is measured here by the number of scientific publications (i.e. articles) appearing in the journals recorded in the *Science Citation Index* (*SCI*) and *Compumath* databases established by the Institute for Scientific Information (ISI), Philadelphia, USA. The humanities and social sciences are not included, since their pattern of publication is not internationalized at all, and prevents any meaningful comparisons between countries.

Sources: ISI data (*SCI, Compumath*); OST treatments, 1995.

FINANCIAL AND HUMAN RESOURCES

An examination of the gross expenditure on R&D activities (GERD) in the various areas of the world (Table 1) serves to underline the dominant role played by the member countries of the OECD, which together account for about 85% of the total world expenditure on science and technology. It is important to note that, with the recent economic developments and a reappraisal of exchange rates, China, India and the newly industrialized countries (NICs) together account for almost 10% of the world's R&D. If Japan, Australia, New Zealand and the other countries of the Far East are added, then the figure is in excess of 26%.

When measured against gross domestic product (GDP) – for which OECD countries account for only about 62% – another characteristic of GERD activities appears: they are more concentrated than economic activities in general. More precisely, the USA and Japan have the highest GERD/GDP ratio, with a value of 2.8%, Europe (the European Union and EFTA countries taken

TABLE 4
SCIENTIFIC PRODUCTION PER DISCIPLINE, MEASURED BY PERCENTAGE SHARE OF PUBLICATIONS, 1993

Scientific disciplines	Europe[1]	Commonwealth of Independent States	North America	Latin America	Muslim countries[2]	Sub-Saharan Africa	Industrial Asia[3]	Other countries of Far East[4]	Australia and New Zealand
Clinical medicine	41.0	1.4	41.4	1.3	0.9	1.2	8.1	1.6	3.2
Biomedical research	36.8	2.9	44.9	1.3	0.4	0.5	9.5	1.4	2.3
Biology	31.5	2.2	43.6	2.5	1.2	2.1	7.6	3.3	6.0
Chemistry	36.9	9.9	27.9	1.3	1.7	0.5	14.0	6.1	1.7
Physics	34.4	10.7	32.8	1.9	0.8	0.3	11.7	6.1	1.3
Earth and space sciences	32.7	5.7	45.5	2.1	1.1	1.2	4.1	3.5	4.1
Engineering sciences	29.6	4.3	44.0	0.9	1.6	0.4	12.6	4.8	1.8
Mathematics	38.0	4.8	39.7	1.6	1.2	0.6	6.3	5.6	2.3
All disciplines	36.5	4.8	39.8	1.5	1.0	0.8	9.5	3.4	2.7

Note: In this table, we have grouped certain regions together in order to arrive at values for 'continents'.

1. EU plus EFTA plus CEEC.
2. North Africa plus Near and Middle Eastern countries.
3. Japan plus the NICs.
4. India, China and others.

Sources: ISI data (*SCI*, *Compumath*); OST treatment, 1995.

together) and Israel being around 2%. Canada, Australia and New Zealand, the Central and Eastern European countries and the NICs are in an intermediate position with ratios between 1.2% and 1.5%.

India, China and countries of the Commonwealth of Independent States (CIS) have GERD/GDP values close to 1%, whilst the remaining regions of the world have a ratio below 0.5%, with notable exceptions at country level within these regions (for example, South Africa, Brazil and Argentina have values well above average for their regions).

When we consider the distribution of R&D personnel in the world (Table 2), another picture emerges: one in which the OECD countries account for only half the world's scientists and engineers, and where the Asian countries from India to Japan possess almost one-third of the global total. Africa accounts for 6%, Latin America for 4% and the Middle and Near East countries for 3%.

If the figures are looked at in relation to the total population, a clear distinction can be made between industrialized countries (with a ratio equal to or greater than 2.0 per 1 000 and reaching a high of 4.1 for Japan) and developing countries (with a ratio between 0.1 and 0.4 per 1 000). The CIS countries and the NICs find themselves in an intermediate position with 1.6 and 1.5 per 1 000 respectively.

SCIENTIFIC PRODUCTION

The scientific production figures for the various regions of the world, as measured by publication rate (Table 3), show the dominance of North America, with about 40% of world share, and Europe (EU, EFTA and the Central and Eastern European Countries together) with over 35%. The OECD countries account for almost 85%, a proportion similar to that of their R&D spending. The countries of Asia from India to Japan (and including Australia and New Zealand) account for only 15.6% of the world total, significantly below their share of research spending.

An analysis of the global scientific publication totals over the past 10 years shows a sharp contrast between the drastic diminution of the CIS countries – with a reduction by almost a factor of two – and the dramatic increase of the share of the NICs and China – with increases by factors of 4.1 and 3.5 respectively.

Latin America, North Africa, the Middle and Near East and other countries of the Far East are developing regions that have increased their share of scientific production. Of the industrialized countries, it is the members of the European Union, Canada and – even more so – Japan, that are increasing their share.

TABLE 5

TECHNOLOGICAL PRODUCTION, MEASURED BY PATENTS GRANTED IN EUROPE AND THE USA, 1993

	European patents		US patents	
	World share 1993 (%)	1993 (base 1987 = 100)	World share 1993 (%)	1993 (base 1987 = 100)
European Union	45.4	91	18.6	76
European Free Trade Association	3.2	86	1.5	73
Central and Eastern European Countries	0.2	58	0.1	41
Israel	0.4	124	0.4	114
Commonwealth of Independent States	0.2	174	0.1	54
USA	27.3	103	48.7	105
Canada	0.8	82	2.3	105
Latin America	0.1	120	0.2	102
North Africa	0.0	–	0.0	–
Middle and Near East	0.0	–	0.0	–
Sub-Saharan Africa	0.1	68	0.1	73
Japan	20.9	129	25.0	111
NICs	0.5	241	1.3	189
China	0.0	–	0.1	153
India	0.0	–	0.0	–
Other countries in Far East	0.0	–	0.0	–
Australia and New Zealand	0.6	59	0.5	79
World total	**100.0**	**100**	**100.0**	**100**

For definitions of the regions of the world, see Table 1.

The individual values may not add up to the totals because of rounding.

Note: European patents here refer to patents taken out through the 'European system' of patenting, which is a procedure by which a patent can be established in several European countries at the same time; US patents refer to patents taken out in the US patenting system.

Sources: INPI/EPO and USPTO data; OST and CHI-Research treatments, 1995.

TABLE 6
INDICES OF SCIENTIFIC AND TECHNOLOGICAL PRODUCTION RELATED TO GDP, 1993

	Index to GDP of		
	Scientific publications	European patents	US patents
European Union	126	181	73
European Free Trade Association	176	330	157
Central and Eastern European Countries	295	32	16
Israel	376	140	146
Commonwealth of Independent States	235	10	4
USA	144	112	200
Canada	202	37	103
Latin America	33	3	4
North Africa	59	–	–
Middle and Near East	25	–	–
Sub-Saharan Africa	83	13	11
Japan	81	208	251
NICs	42	15	38
China	9	–	–
India	54	–	–
Other countries in Far East	3	–	–
Australia and New Zealand	191	44	38
World total	100	100	100

For definitions of the regions of the world, see Table 1.

Note: the shares of world scientific publications, and of European and US patents, have been divided by the GDP of the regions in question; the world value for the index (the average value) has been set at 100 for easier reading.

Sources: ISI (*SCI* and *Compumath*); INPI/EPO and USPTO data; OST and CHI-Research treatments, 1995.

The various regions of the world exhibit specializations (or strengths) to their science: in other words, disciplines in which they have a world share above their overall scientific publication share. In a similar way, they have disciplines of de-specialization (or of relative weakness) (Table 4).

Europe has a relatively balanced profile, but with its strength in clinical medicine and a relative weakness in the engineering sciences. North America has a somewhat different profile, with its strong areas being biomedical research, earth, space and engineering sciences, and the weak area chemistry. Industrialized Asia shows a completely different pattern, with strong points in chemistry, physics and engineering sciences, while biology is just below average, and mathematics and the earth and space sciences further below.

The CIS countries appear very weak in biology and very strong in physics, chemistry and the earth and space sciences.

The less-developed continents tend to show a specialization in the earth and space sciences and biology and relative weakness in biomedical research. The Muslim countries and countries of the Far East other than Japan and the NICs exhibit a preference for chemistry, engineering sciences and mathematics, while Latin America gives more emphasis to physics.

TECHNOLOGICAL PRODUCTION

As indicated by European patenting figures (Table 5), the major technological capabilities are shared by Europe (nearly 50% of world total), the USA (27%) and Japan (21%). No other country is above 1%. In terms of evolution, the EU countries have lost 9% of their share in six years (index 91), while the USA has gained 3% and Japan 29%; the NICs have multiplied their share by 2.4 during that same period.

Seen through US patenting data, the picture is different in certain respects: the USA accounts for 48.7%, while the EU and Japan account for 18.6% and 25% respectively, which indicates that Japan is stronger in the USA than in Europe. Furthermore, Japan is becoming ever stronger (an increase of 11% in its share in six years), and the USA slightly stronger

TABLE 7
FINANCING AND IMPLEMENTATION OF R&D IN THE TRIAD, 1992

	European Union[1] (%)	USA (%)	Japan (%)	Total (%)
GERD financing				
public civil financing	37.8	16.9	22.5	25.7
public military financing	9.4	24.0	1.4	11.6
industry	52.8	59.1	76.1	62.7
Total financing	100.0	100.0	100.0	100.0
GERD implementation				
public research institutions	18.1	14.5	12.9	15.2
university	18.9	12.9	13.6	15.1
industry	63.0	72.6	73.5	69.7
Total implementation	100.0	100.0	100.0	100.0

1. EU: the 15 member countries of the Union as of 1995: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden and the UK.

Sources: OECD; OST treatment, 1995.

(an increase of 5% over the same period); the EU countries are in sharp decline (a 24% decrease). A significant feature of the situation in US patenting is the share of the NICs, which is almost 1.3%. Already 55% of Canada, 5% of Japan and 7% of the EU countries, this share has almost doubled over the six years in question.

By dividing the world shares by the GDP of the regions, it is possible to compare scientific and technological production whilst avoiding the size effect of their respective economies (Table 6).

The most 'scientifically oriented' countries or regions in terms of scientific publications are then Israel, the Central and Eastern European countries, the CIS countries, Canada, Australia and New Zealand (twice to four times the average index). At around 50% above average come Europe (the EU and EFTA) and the USA. Japan holds a modest position here (19% below average), with an index similar to that of sub-Saharan Africa.

TABLE 8
TECHNOLOGICAL PRODUCTION AND ITS EVOLUTION IN THE TRIAD, MEASURED BY EUROPEAN AND US PATENTING, 1987-1993

	European patents world share (%)		US patents world share (%)	
	1987	1993	1987	1993
European Union[1]	49.9	45.4	24.4	18.6
USA	26.6	27.3	46.3	48.7
Japan	16.2	20.9	22.5	25.0

1. EU: the 15 member countries of the Union as of 1995: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden and the UK.

Sources: INPI/EPO and USPTO data; OST and CHI-Research treatments, 1995.

TABLE 9

THE POSITIONS OF THE TRIAD BY TECHNOLOGICAL AREA, MEASURED IN PATENTS, 1993

	European patents world share (%)			1993 (base 1987 = 100)		
EUROPEAN	European Union[1]	USA	Japan	European Union[1]	USA	Japan
Electronics/electricity	34.2	30.0	31.8	83	101	129
Instruments/optics	37.8	32.4	23.4	84	106	136
Chemistry/pharmaceuticals	40.3	33.7	20.0	95	103	107
Industrial processes	50.1	25.6	16.6	95	100	125
Mechanical engineering/transport	58.5	19.2	15.5	96	100	134
Consumer goods	64.0	16.9	8.0	99	98	142
All fields	45.4	27.3	20.9	91	103	129

Sources: INPI/EPO (EPAT) data; OST treatments, 1995.

	US patents world share (%)			1993 (base 1987 = 100)		
UNITED STATES'	European Union[1]	USA	Japan	European Union[1]	USA	Japan
Electronics/electricity	11.5	46.7	35.4	64	98	117
Instruments/optics	14.9	50.8	28.0	74	111	100
Chemistry/pharmaceuticals	28.2	51.0	19.7	90	103	108
Industrial processes	22.3	50.5	19.3	79	106	115
Mechanical engineering/transport	23.6	45.4	22.5	80	110	102
Consumer goods	19.1	50.1	12.5	76	103	106
All fields	18.6	48.7	25.0	76	105	111

1. EU: the 15 member countries of the Union as of 1995: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden and the UK.

Sources: USPTO data; OST and CHI-Research treatments, 1995.

When examining the technological content of the economies, on the other hand, the performance of Japan is striking: twice the average in European patenting, and 2.5 times in American patenting, which is a higher index than the Europeans in Europe or the Americans in the USA (index 208 against 181 for Europe, index 251 against 200 for the USA). The performances of the EFTA countries (Switzerland and

Norway, basically) and Israel are also noteworthy. The USA appears relatively strong in American patenting (index 200), and in European patenting (index 112), whereas Europe is relatively strong in its own market (index 181), but weak with respect to exports overseas (index 73 in American patenting).

An important feature is the index of the NICs, which is more than half the level of EU countries in American patenting (index 38 as against 73).

COMPARISON BETWEEN EUROPE, THE USA AND JAPAN

The origins of R&D funding are strikingly different in the three regions of the 'Triad' (the EU, USA and Japan) (Table 7). Thirty-eight per cent of funding comes from public civilian sources in Europe (and only 17% in the USA), 24% from military funds in the USA (and only 1.4% in Japan), 76% from industry in Japan (and only 53% in Europe). The pattern of R&D implementation is more similar. Between 13% and 18% of R&D is performed in public research institutions, between 13% and 19% in universities and between 63% and 74% in industry.

The countries of the EU continue to exhibit good technological capability in Europe (measured in world share of European patents), with the USA having quite levelled off; but they have lost 4.5 percentage points in six years, while Japan has gained 4.7 points during the same period (Table 8). In world share of US patents, the USA has gained 2.4 percentage points in six years, arriving at a good 48.7% share, and the EU countries have lost 5.8 points. Meanwhile, Japan has gained 2.5 points, now at 25%, which is about 50% of the share of the Americans themselves.

In Europe, the three regions of the Triad enjoy almost the same share of the electronics/electricity area, the USA being also particularly strong in instruments/optics, as well as in chemistry/pharmaceuticals, where it comes close to Europe (Table 9). The Europeans are strong, and stay strong in most areas, but lose ground particularly in electronics/electricity (minus 17% in six years) and instruments/optics (minus 16%). The Japanese show sharp increases in all areas, including consumer goods, except for chemistry/pharmaceuticals. The USA shows an unchanged profile.

In the electronics/electricity area, Japan has more than 75% of the amount of American patents registered by the Americans themselves (35.4% as against 46.7%), and appears well in the instruments/optics area. The EU countries are particularly weak in those areas, but show better in chemistry/pharmaceuticals and mechanical engineering/transport, where they are above Japan, and in the latter case, at more than 50% of the Americans (23.6% as against 45.4%).

During the last six years, the USA slightly increased its world share in American patenting, except in the electronics/electricity area where it lost 2%. In that same area, the EU countries have lost 36% of their already modest share; in all the others they have lost 10% or more. Japan has gained ground in all areas; in electronics/electricity the increase has been 17% in six years.

THE INTERNATIONAL MOBILITY OF STUDENTS

More than 1.3 million students currently go into a foreign country for their studies, or part of their studies (Table 10). Most of these internationally mobile students come from the EU countries, the CIS countries, the Middle and Near East, the NICs and China.

In terms of expatriation rates, after Israel, the highest rates are those of the Middle and Near East countries, as well as African countries on one side, the NICs and China on the other. Students from the USA are the least internationally mobile.

The USA receives about 0.4 million foreign students per year and Europe 0.5 million, which amounts to about 70% of the world total; Japan receives only about 3.3% (Table 11). In several

TABLE 10
INTERNATIONAL MOBILITY OF STUDENTS, 1992

	Total student population ('000s)	Students studying abroad ('000s)	Proportion of students abroad (%)
European Union[1]	10 740	232	2.2
European Free Trade Association[1]	326	18	5.5
Central and Eastern European Countries[1]	1 639	42	2.6
Israel	149	23	15.6
Commonwealth of Independent States	5 283	122	2.3
USA	14 556	25	0.2
Canada	2 001	26	1.3
Latin America[1]	7 715	73	1.0
North Africa[1]	1 834	90	4.9
Middle and Near East[1]	3 407	153	4.5
Sub-Saharan Africa[1]	1 393	84	6.0
Japan	2 918	55	1.9
NICs[1]	2 581	132	5.1
China	2 302	129	5.6
India	4 936	43	0.9
Other countries in Far East[1]	5 918	60	1.0
Australia and New Zealand[1]	711	15	2.1
Non-specified	–	32	–
World total	68 408	**1 354**	**2.0**

For definitions of the regions of the world, see Table 1.

1. Including intra-zone mobility.

Sources: UNESCO data; OST treatment, 1995.

European countries (the UK, France, Belgium and Austria) the proportion of foreign students is above 6%. In Switzerland it is 16.9%; the proportion is also fairly high in such other countries as Australia.

TABLE 11
COUNTRIES RECEIVING THE MOST FOREIGN STUDENTS, 1992

	Foreign students in the country ('000s)	Share of total foreign students received (%)	Proportion of foreign to total students in the country (%)
USA	439	32.4	3.0
France	138	10.2	7.0
Commonwealth of Independent States	134	9.9	2.5
Germany	117	8.6	4.7
United Kingdom	88	6.5	6.3
Japan	45	3.3	1.5
Australia	39	2.9	7.0
Canada	37	2.8	1.9
Belgium	27	2.0	9.8
Switzerland	25	1.9	16.8
Austria	22	1.6	9.7
Italy	21	1.5	1.3
Total, leading countries	1 132	83.6	–
World total	**1 354**	100.0	2.0

Sources: UNESCO data; OST treatment, 1995.

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North America

RODNEY W. NICHOLS AND J. THOMAS RATCHFORD

The enterprises of science and technology (S&T) across North America – encompassing Canada, Mexico and the USA – are generally healthy. At the same time, however, the scientific community faces relentless retrenchment as governments, firms and universities tighten budgets. Similarly, the technological community confronts shorter timetables to meet sharpened economic goals. Both communities are more concerned with faster and more efficient transfer of knowledge: university and government laboratories with supply-side 'dissemination' of scientific results, and industrial technologists with demand-side 'search' for technology. This chapter highlights trends in each country as well as regional activity and global comparisons. National profiles reveal the paradox of rising expectations for rapid progress in research and increasing constraints on finance for the work.

Context

The combined average annual spending on research and development (R&D) during the period 1992-94 for all three countries was roughly US$180 billion. This effort serves about 400 million people, with a combined gross domestic product of US$7 trillion. North American investment was almost 45% of the worldwide total funding for R&D. Recently, both governments and firms have emphasized increasingly specific, short-range objectives. While aware of the growing requirements for international cooperation in science, each nation also aims for technological competitiveness in the global market for its products and services.

This North American grouping of three countries is somewhat arbitrary, given the substantial differences in population, language, level of economic development and other factors. However, the North American Free Trade Agreement (NAFTA) has given the region a fresh sense of economic coherence and a more favourable trading environment. Regional linkages in S&T, still modest overall, continue to expand and yet lag behind the economic integration. The R&D links involve expanded private alliances and investments, diverse exchanges through professional societies and academic institutions and government-organized consultations and programmes.

Changes and continuities in policy

In the USA during 1994 the federal government pursued presidential initiatives to accelerate the commercialization of promising technologies by building new partnerships between government and industry. Programmes for developing a 'clean car' and for aiding defence firms in their conversion to civilian purposes, were examples of this new thrust. In early 1995, however, as Congress convened under the control of the Republican Party, significant re-evaluations were underway; and cutbacks were anticipated in government funding for such industry-oriented initiatives.

For the USA generally the most important influence on governmental science policy during the mid-1990s is the acute budgetary austerity that puts all public R&D investment under the most searching scrutiny. As a result US academic institutions and medical centres are facing pervasive challenges to their traditional ambitions, finances and organizational arrangements. Comparable financial strains in Canada and Mexico impose even more severe constraints on research.

In parallel, dramatic changes have occurred in US industrial R&D. Although total business-funded R&D increased 140% during the whole period between the mid-1970s and the mid-1990s, such funding has been flat for the past few years. Corporate sponsorship of basic science has changed, with a much greater emphasis on the short term, while R&D in the service industries has grown substantially. Many firms have imposed much shorter-range R&D objectives because product improvements must be made more rapidly. In Canada and Mexico, just as industrial R&D was picking up momentum to help meet global trade objectives, the national economic downturns have suppressed both public and private investment.

Despite the economic pressures the region also displays many underlying continuities in policy. These include concerted efforts to:

- improve elementary and secondary education in science and mathematics, which is seen as crucial for preparing the future workforce;
- emphasize centres of research excellence, which is viewed as important as a protection from across-the-board funding cutbacks;
- design R&D performance criteria, which is visualized as encompassing not only the quality of scientific and engineering efforts but also their relevance to economic payoffs.

Opportunities for research

Research scientists, engineers and physicians in North America are among the global leaders across most scientific frontiers. Owing to the limitations of space in this report, only a few brief illustrations will be given to suggest the extraordinary opportunities in contemporary research.

In the life sciences, stunning advances at the molecular level of understanding the mechanisms in genetics, immunology, virology and neuroscience continue to underpin the development of improved pharmaceuticals and medical devices. The life sciences not only pave the way for progress in medicine but also enhance the base for modern agriculture. Hope rises for solving such daunting medical problems as AIDS, Alzheimer's disease, cancer and heart disease.

Similarly, deepening work on the environment – arguably the most interdisciplinary of research subjects because of the challenge to integrate biological, physical and human sciences – is clarifying how climate change affects the planet. New environmental S&T helps to shape prudent economic paths for environmental protection. Furthermore, most estimates suggest a booming global market for environmental technologies embodied in new products and services.

Materials science and engineering – also animated by cross-disciplinary activities – pull together physicists, chemists, ceramicists, metallurgists and others, with increasingly powerful analytical instruments. These efforts range over studies of the composition of matter and reveal how to exploit deeper knowledge for designing new materials and improving manufacturing techniques.

Sparkling progress in the information sciences and telecommunications encompasses both hardware and software. Not only does performance continue to double every two years, but prices decline. High-performance computing and information networks promote the effectiveness of every industry and institution and enable investigators to communicate with collaborators more intensively and efficiently. Further, modern data handling enhances the depth, range and productivity of most lines of research – on the brain, the oceans, the human genome and the origins of the universe.

During the last decade of the 20th century there are daily reminders of Pasteur's insight: 'There is only one science and the application of science, and they are bound as the fruit is to the tree'. This century is often characterized as the golden age of science. Yet the benefits and consequences of pursuing these promising frontiers are often unpredictable. Throughout North America, working scientists and research executives are frustrated by trying to reconcile the conflicts posed in framing an agenda that responds to the open-ended opportunities for long-term research as well as to the narrower objectives imposed by urgent social and economic goals. Many observers see a growing risk of underinvestment in the global reservoir of basic science from which all countries draw to provide the next generation of talent.

Scope of review

This review gives special attention to recent US experience in three domains: those of industrial R&D, university-industry collaboration and defence

R&D. Across every region such experience should be shared to clarify the lessons learned in forming productive public-private coalitions and in organizing the adaptation of firms, universities and national laboratories from traditional objectives to more market-driven missions.

The discussion treats R&D expenditure throughout the public and private sectors. A broader definition of 'S&T in society' would have to take into account the myriad jobs that require a measure of scientific and mathematical literacy and use advanced technological tools; but that is not the task here. Instead, this review concentrates on the professional and supporting functions normally associated with the programmes and infrastructure typified in the data organized by the Organisation for Economic Co-operation and Development (OECD), UNESCO and national sources to define R&D. Because most governments now attach greater importance to weighing quantitative international comparisons and, in particular, to monitoring R&D investments by the private sector, broader analyses will be needed in order better to understand both North American and global indicators.

INVESTMENT IN S&T

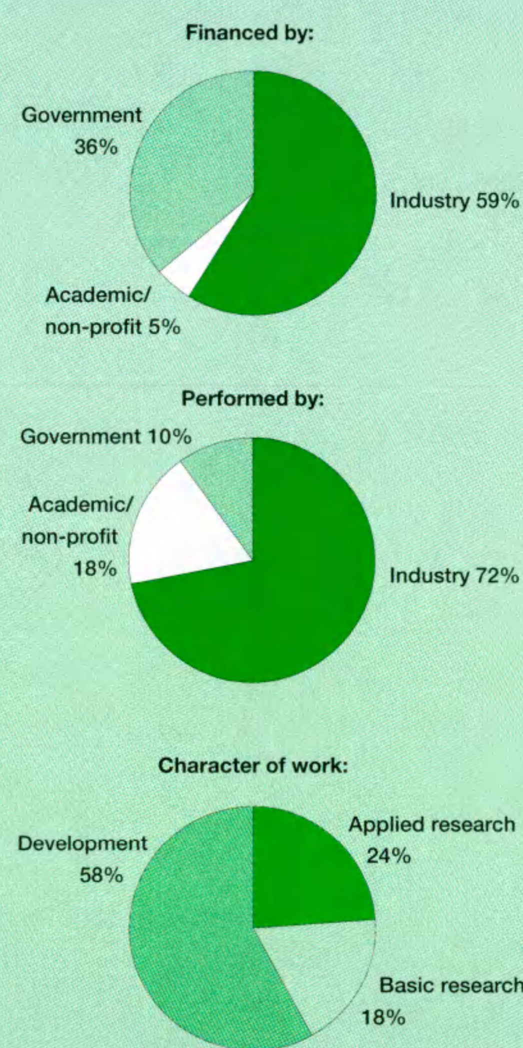
This section summarizes the overall expenditure and the major performers of R&D. Selected comparative indicators show related trends in human resources, along with economic baselines.

Overall R&D expenditures

Figure 1 portrays the 1994 investment in R&D, including basic science, for the USA. The early 1990s was a period of gradual accommodation to increasingly tight budgets for all R&D in both the public and private sectors. A plateau has been reached in funding for most fields of science and engineering. A few applied areas continue to experience significant growth, e.g. climate change research in the public sector and software development in the private sector.

FIGURE 1
US R&D EFFORT, 1994

Total national spending US$173 billion
Percentage of GDP 2.6%
Real growth 1%

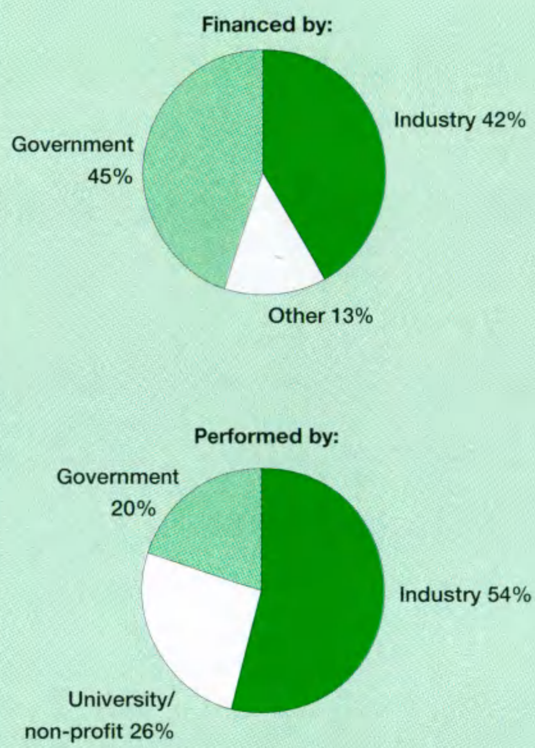


Sources: NSF, 1994; AAAS.

For Canada (Figure 2) and Mexico (Figure 3) similar data show the patterns for 1993 and 1991-92 respectively. Definitions differ among countries, and data for a variety of years are the best available information; so precise comparisons across the region are not feasible. Striking national economic difficulties in Mexico during 1995, and extremely tight governmental budgets in Canada, are the most important overall changes affecting their R&D in recent times.

FIGURE 2
CANADIAN R&D EFFORT, 1993

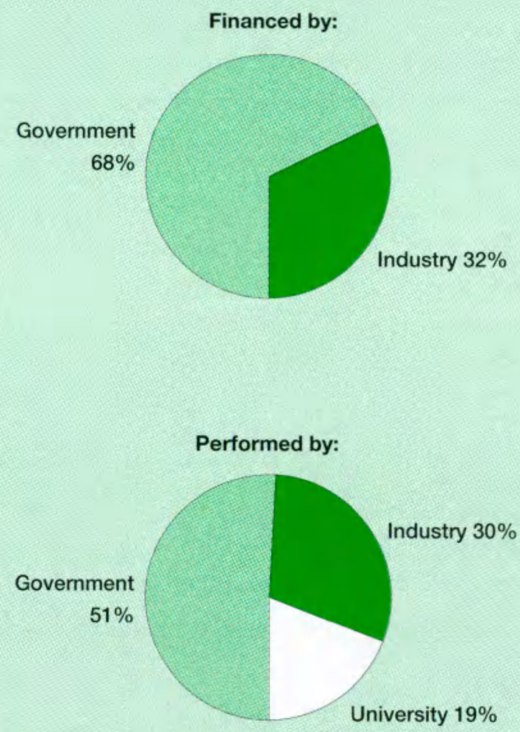
Total national spending US$8.5 billion
Percentage of GDP 1.5%
Real growth 1.9%



Sources: NSF, 1994; Industry Canada, 1994; OECD, 1994.

FIGURE 3
MEXICAN R&D EFFORT, 1991-92

Total national spending US$1.5 billion (1991)
Percentage of GDP 0.3%
Real growth 2% (est.)



Sources: CONACYT, 1994; OECD, 1994; NSF, 1994.

Comparative indicators

To help diagnose the R&D intensity of the three countries within their national contexts and with respect to global trends, Table 1 brings together various data from the World Bank, the United Nations Development Programme (UNDP) and OECD. The North American region confirms a pattern seen elsewhere: the level of industrialization correlates with the level of private R&D, and as the private sector plays a more prominent role, so governmental laboratories are less significant. Such correlations assuredly do not, however, explain how best to synchronize and sustain the crucial details of S&T priorities with national economic policy.

TABLE 1
SELECTED COMPARATIVE INDICATORS

	USA 1994	Canada 1993	Mexico 1991-92
Total R&D spending (US$ billions)	173	8.5	1.5
Total R&D as % GDP	2.6	1.5	0.3
% total R&D			
performed by industry	72	54	30
financed by industry	59	42	32
performed by government	10	20	51
performed by academic/non-profit	18	26	19
Population (1992) (millions)	255	27	88
Real GDP/capita (1991) (US$ '000s PPP[1]) (World aggregate is 5.5)	22.1	19.3	7.2

1. Purchasing power parity.

Sources: UNDP, 1994; NSF, 1994; World Bank, 1994.

Human resources

The foundation for a vigorous R&D programme is the talent in the educational system as well as in science, engineering and medicine. Table 2 portrays selected indices of the base of human resources for R&D in the three North American countries. As is true for other series of data, definitions differ and time periods are not strictly comparable. Nonetheless, it is clear that Mexico lags behind in the evolution of an R&D-intensive economy; and accordingly, despite economic strains in 1995, the high priority Mexico has been assigning to S&T will probably be maintained as it continues to industrialize and prepare a technically trained workforce.

TABLE 2
SELECTED DATA ON HUMAN RESOURCES FOR R&D BASE (DATA FROM ABOUT 1990)

	USA	Canada	Mexico
Total R&D scientists and engineers ('000s)	950	63	10
Scientists and engineers in R&D per 10 000 labour force	76	46	5
% scientists and engineers in manufacturing			
Science	21	39	na
Engineering	79	61	na

na = not available.

Sources: NSF-NSB-93-1; UNDP, 1994; World Bank, 1994; OECD, 1994.

SCIENCE IN THE UNIVERSITIES

Throughout the North American region universities confront a triple challenge: applied goals delimit their research and educational missions, strict austerity constrains their funding and higher levels of accountability measure their performance. The remainder of the 1990s will be a difficult era of accommodation to these new demands.

Many observers see a period in which entirely new forms of organization may emerge. Research universities will be compelled not only to shrink their range and level of activities, but also to reconstruct the terms and

TABLE 3
ACADEMIC EXPENDITURE ON R&D, 1992

	Expenditure (US$ billions)	% national R&D	% GDP
Canada	2.2	23	0.40
Mexico[1]	0.3	19	0.06
USA	24.0	14	0.40

1. 1991.

Sources: UNDP, 1994; NSF, 1994; World Bank, 1994.

expectations of agreements with industrial firms and governmental sponsors. At the same time, colleges and universities must renew their commitment to training students even more broadly. In the increasingly competitive workplace, technological change impels increased adaptability and mobility for everyone, either in professional science and engineering or in jobs throughout the rest of the economy.

The most recent data on academic expenditure on R&D are summarized in Table 3. As noted below, trends during the past year have been characterized by a growing squeeze on such expenditure.

Canada

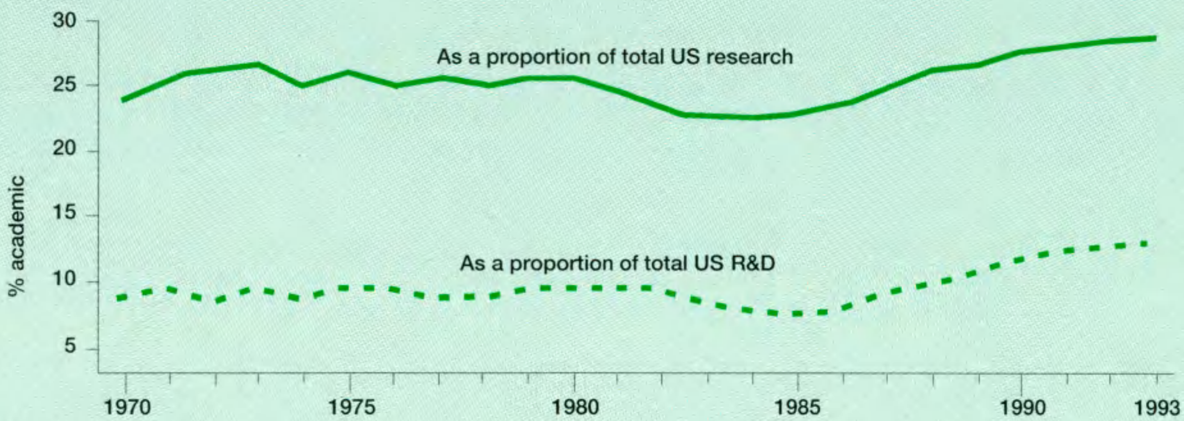
Research budgets at universities in Canada will evidently be cut sharply during 1995 and will decrease further over the coming two or three years. One estimate is that academic science will decline by about 15% in current dollars (which will amount to a larger cut in buying power) over the period from 1995 to 1998. Projections are still uncertain in mid-1995, so it is impossible to gauge their impacts in detail. Nonetheless, given the estimated 35-40% reduction in overall Canadian government R&D support over the next few years, universities continue to be given a comparatively high priority within Canadian science.

The Canadian government assigns continuing emphasis to the process of pushing research towards the more rapid commercialization of results, even as industry-oriented technology programmes face the largest reductions in funding. Universities are viewed as a key partner in this emphasis. Whether projects concern space, social science or medical research, budgets will be limited and priorities will be refocused. Unfortunately, because the overall responses by universities were not yet adapted during mid-1995 to the recent budgetary changes, historical time-series about funding across fields are not relevant to interpreting current and prospective trends. A thinning out of efforts with long-range timetables in basic research may occur, as it has in other countries facing similar constraints on funding and similar demands for short-range economic relevance. Should such a trend take hold, it may become a disincentive for doctoral education in science and engineering as well as restrain the scale and scope of Canadian participation in international research cooperation.

Mexico

With the sharp downturn in the value of the peso during early 1995, Mexican investment in all sectors has been cut. Education generally and academic science in particular have been affected adversely in a variety of ways. But it remains difficult to interpret how seriously the cutbacks will retard what had been an extraordinary renewal of Mexican research during the early 1990s. The March 1995 announcement of the creation of a Mexican National Research Foundation – akin to the US National Research Council – is an illustration of the rising recognition of the importance of organizing scientific panels to address major policy issues. This process in turn should underscore the priority for building a scientific and academic base for economic and social goals. However, in the light of the fiscal austerity in 1995, both governmental and industrial resources for university research are likely to be extremely scarce for most of the rest of the 1990s.

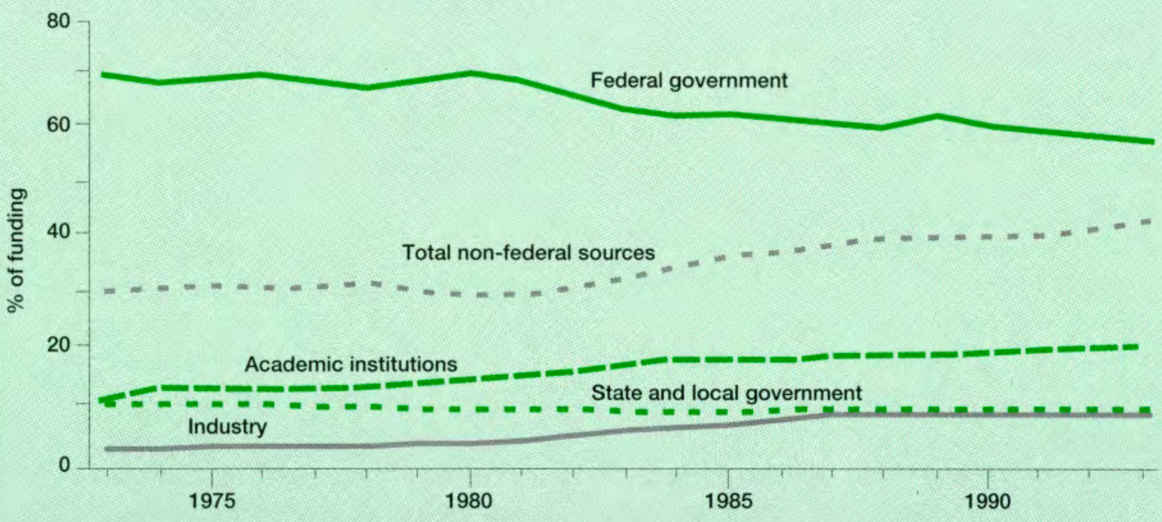
FIGURE 4
ACADEMIC R&D AND RESEARCH AS A PROPORTION OF US TOTALS



Notes: Academic research includes basic research and applied research. Data for 1992 and 1993 are estimates.

Source: NSB, 1993.

FIGURE 5
SOURCES OF US ACADEMIC R&D FUNDING BY SECTOR



Note: Data for 1992 and 1993 are estimates.

Source: *Science and Engineering Indicators*, 1993.

United States of America

During past generations, campuses in the USA have become increasingly dependent on external support for their basic scientific activities. It is of major concern that the diverse missions undertaken for external sponsors undercut the capability of universities to function independently and to conduct the core functions of research and education with students at all levels. The squeeze is severe as universities struggle with further budget cuts and attempt to quell public doubts about the utility of basic science. The post-Second World War 'social contract' between universities and the American public is being renegotiated.

A key indicator of both health and vulnerability is that academic R&D has increased over the past 20 years both as a proportion of total US research and as a proportion of total US R&D. Figure 4 shows these trends. So universities naturally experience increasing demands to sustain these investments. However, Figure 5 shows that the federal government's support for academic R&D has declined slowly over the past 20 years, reducing from almost 70% of the total funding of university R&D in 1973 to less than 60% in 1993. During this interval non-federal sources have grown from about 30% to more than 40%, and academic institutions have increased support of their own work by almost a factor of two. Although industrial funding has risen for a variety of reasons, it remains a comparatively small fraction of total academic R&D funding.

The data in Table 4 show the trends for basic research, long a dominant mission of major American universities. Over the past 30 years (1965-94), research-oriented campuses have almost tripled their effort. The apparent increase in industrial basic science during the past decade is largely attributable to improved and broader sampling of actual activity rather than to an overall higher priority by firms, as is explained in more detail below. Given the national mood and economic situation in the USA during 1995, however, it is highly unlikely that there will be any substantial growth in funding for academic basic science during the next few years.

TABLE 4
FUNDING AND PERFORMANCE OF US BASIC RESEARCH (1987 US$ BILLIONS)

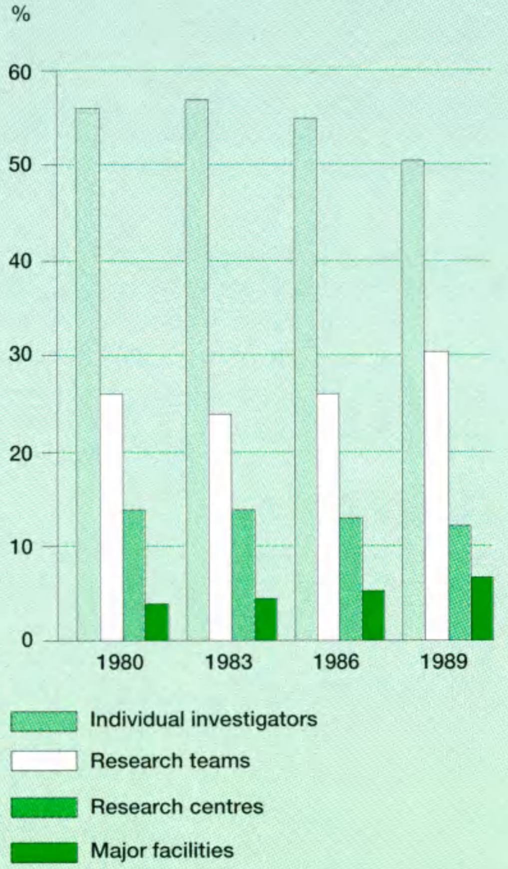
	1965	1975	1985	1994
Funding				
Total US	9.0	9.9	15.0	25.0
Federal government	6.4	6.8	9.7	15.0
Industry	1.6	1.4	3.0	5.9
University/college	0.6	1.0	1.5	2.9
Non-profit	0.4	0.6	0.7	1.2
Performance				
Total US	9.0	9.9	15.0	25.0
Federal government	1.3	1.5	2.0	2.2
Industry	2.1	1.5	3.0	7.6
University/college	4.0	5.1	7.0	11.1
Non-profit, other	1.6	1.8	3.0	4.1

Sources: NSF, 1994.

Two other indicators reveal the stresses on American academic investigators and research executives. One, illustrated in Figure 6, is that the percentage of funding to 'individual investigators' dropped over the decade of the 1980s. While the decrease is not large, from a little more than 55% to about 50%, this decline corroborates the fact that the competition for smaller grants has become even more severe. It would be an oversimplification to say that this is an unambiguous index of crowding out 'curiosity-oriented research'. Nonetheless, the increased efforts of larger teams, new research centres and major facilities have made it increasingly difficult to support the large number of qualified individuals who wish to conduct 'little science' at campuses. This produces a lengthening queue, a falling success rate of applicants for grants, and for many, a bleak outlook.

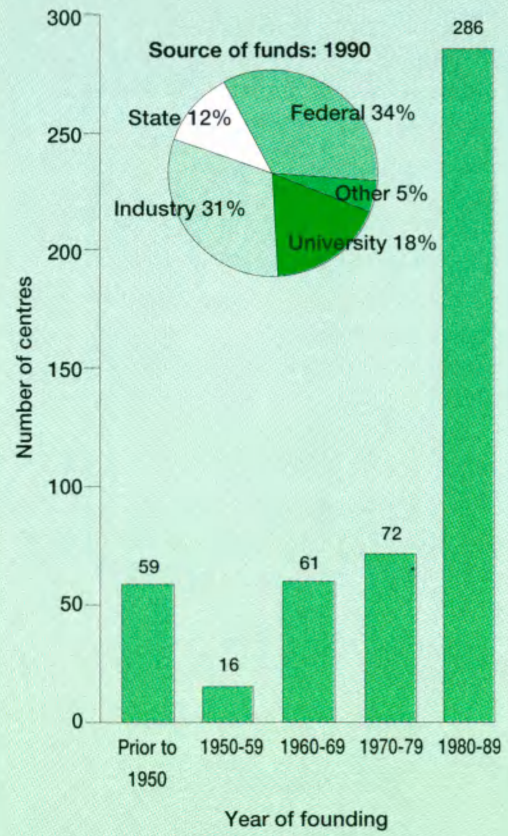
A second indicator of trends in the USA given in

FIGURE 6
FEDERAL NON-DEFENCE RESEARCH FUNDING TO UNIVERSITIES, BY MODE OF RESEARCH SUPPORT



Source: NSB, 1993.

FIGURE 7
GROWTH IN UNIVERSITY-INDUSTRY RESEARCH CENTRES AND SOURCE OF FUNDS



Note: Data are for centres existing in 1990. Of an estimated 1 058 centres, 458 provided funding data and 494 provided founding data.

Source: Cohen, Florida and Goe, 1993.

Figure 7 is the extraordinary growth during the 1980s – roughly a four-fold rise – in university-industry research centres. These centres are not permanent and may not survive as funding decisions are made. But for the previous 30 years, such centres were only a minor feature on the R&D terrain of the USA. As concern grew for accelerating the commercial application of research by connecting investigators and results to the market, university-industry teams were established and supported generously by a combination of the federal government and private firms, along with state government and university sources. The combination of federal and business funding in 1990 represented about two-thirds of the support of these centres.

For the future, whatever the level of federal funding for basic and applied science, universities will continue to be pressed to contribute more to economic growth. This will lead to broader and deeper ties to commercially oriented R&D enterprises. In turn, US universities will be tempted to become even more sophisticated, aggressive and flexible about exploiting intellectual property rights in areas such as biotechnology, information systems, new materials and electronic devices.

US research universities are reframing their actions and policies on many topics. These include:

- Upgrading obsolescent scientific facilities and equipment, a long-standing problem that surely will not be solved immediately, especially since so little governmental funding will be available.
- Creating opportunities for initial and permanent positions for young investigators generally, including women and minorities – also a long-standing goal and now being complicated by new laws permitting later retirement by senior faculty members.
- The increasingly deep cutbacks at academic medical centres, whose revenues are being reduced as a consequence of national health care cost-controls, thereby reducing funding for research and training for the next generation of investigators.

Outlook

For science-intensive North American colleges and universities, the outlook for the 1990s is conflicted and uncertain. Despite the continuing need for trained scientists, engineers and physicians – not to speak of the growing demand for technically trained support staff in corporate laboratories, financial services, communications, computers and other fields – universities will have to cope with budget cuts in much the way that most firms rethought their functions during the 1980s. At a time of imminent downsizing, clarity on campuses about 'rightsizing' remains elusive. Choices will have to be made about how universities can best enhance their distinctive missions and their productivity while cooperating efficiently with corporate and governmental R&D centres across institutional and geographical boundaries.

S&T IN INDUSTRY

During the past decade companies have made dramatic changes in the process of acquiring the knowledge to drive innovations for new and improved products, processes and services. This section describes these changes. Particular emphasis is given to the USA, where total company-funded R&D is estimated to exceed US$100 billion in 1994, representing over 95% of the company-funded R&D in the region.

Overall trends and comparisons

Company-funded R&D over the past generation has grown substantially faster than government-funded R&D in most nations of the world. For example, in the USA the federal government's R&D funding (in constant dollars) increased by 30% from 1974 to 1994, while company-funded R&D increased by 144%. Table 5 displays industrial R&D for the region as a whole during 1989-94.

TABLE 5
R&D EXPENDITURE IN THE INDUSTRIAL SECTOR

	US$ billions PPP[1]		
	1989	1991	1994 (est.)
Canada	3.7	4.2	4.9
Mexico	0.33	0.5	na
USA	102.0	117.0	124.0

na = not available.

1. Purchasing power parity.

Sources: NSB, 1993; NSF, 94-327; OECD, 1994.

Increases in company-funded R&D in the non-manufacturing (service) industries in the USA have been dramatic in recent years. In 1975 about 3% of the industry R&D total was estimated to have been performed in the service sector. This increased to 9% in 1987 and to 25% in 1992, the year of the latest National Science Foundation (NSF) *Survey of Industrial Research and Development*. This survey is conducted by the Bureau of the Census, Department of Commerce with NSF support. No equivalent statistics are available for Canada and Mexico.

The 1992 NSF survey was designed to be representative of all companies performing R&D in the USA, both publicly and privately held. Its sample size was approximately twice that of the 1987 survey, in order better to represent new companies with R&D activities and to reflect more accurately R&D in the service sector. Surprisingly, the new survey shows an evident discontinuity in 1991 with an increase of about US$15 billion, i.e. comparing the revised 1991 data (collected with the 1992 survey) to those of the 1991 survey; NSF is developing an algorithm to link smoothly the results from the 1987 survey with those of 1992. Table 6 gives the best available data for each decade from 1955 to 1994.

TABLE 6
R&D PERFORMED BY INDUSTRY IN THE USA, 1955-94

	US$ billions				
	1955	1965	1975	1985	1994
Federal	2.2	7.7	8.6	27	26
Company	2.5	6.4	16	57	101
Total	4.6	14	24	84	127

	Constant 1987 US$ billions				
	1955	1965	1975	1985	1994
Federal	9.5	27	17	29	20
Company	11	22	32	60	80
Total	20	50	49	89	100

Source: NSF, 94-327.

The industrial research environment

Over the past generation the character and boundary conditions for industrial R&D changed considerably. These changes have been much more pronounced during the past decade. What some regard as the 'golden age' of corporate research in the USA, i.e. the pattern of large, centralized, long-term research laboratories and programmes, is deemed to have passed and is not likely to return.

Industrial R&D is now relentlessly market-driven. Markets are global, with few pockets of protectionism remaining. In mature industries, such as that of chemicals, the market is defined by the low-cost producer, regardless of either its depth of technology or its geographical location. R&D is one of the costs to be controlled, by cutting in-house programmes, developing technology alliances, or purchasing the needed technology.

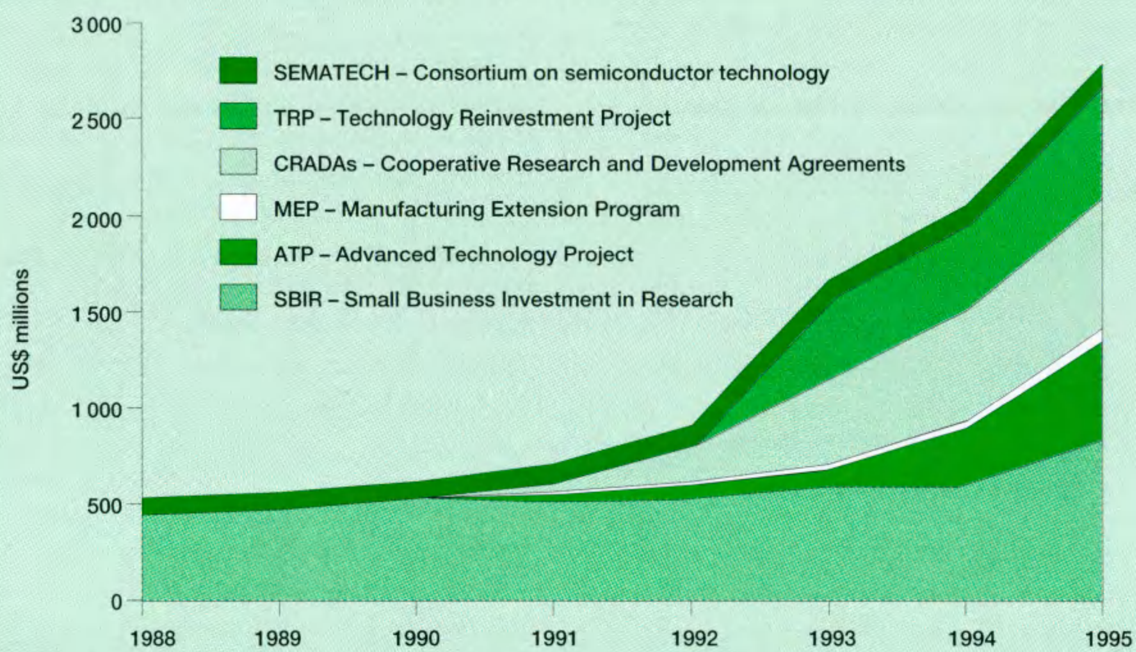
The life-cycles of products continue to decrease. Successful companies must not only innovate well, but quickly. In company laboratories this means shorter and shorter time-horizons for R&D. A three-year time-horizon for an R&D project is now considered to be very long-term. Since a single company can no longer support research in all the important areas of its business, out-sourcing of technology is a commonly used tool. This out-sourcing takes several forms: for example, procurement of R&D, design and engineering services; technology alliances with other firms; participation in R&D consortia; industry-university cooperation; and licensing of technology.

The fate of central research laboratories within major corporations is of special concern to many observers of the R&D scene. In the past these laboratories made discoveries that led to completely new lines of business for the company sponsors. This was possible because of talent and resources devoted to long-term research supported from corporate funds. Given the present emphasis on quick return, and with funding coming almost entirely from the individual business units within large firms, many believe that central research laboratories in the future will provide mainly incremental improvements to existing products, processes and services, and perhaps develop new ones for existing businesses. But these central laboratories will not provide the basis for entirely new businesses. Instead, in the future, a company will enter new areas by investing capital to buy start-up enterprises. It remains to be seen whether this will be a better use of company resources than sustaining corporate laboratories conducting long-term research.

US Government technology policy

With the inauguration of President Clinton in January 1993, the federal government moved swiftly to implement a new technology policy. The Clinton policy, issued in February 1993, featured proposals for dramatic increases in federal funding of technology development, acceleration of technology diffusion and commercialization through Manufacturing Extension Centers and other initiatives and a shift in the federal civil/military R&D ratio from 41/59 to 50/50. The major funding increase proposed in R&D was for technology development. By contrast, the Bush administration's technology policy, issued in September 1990, had mentioned increased funding only for basic research. Funding of technology development has emphasized federal programmes based on partnerships with industry. Figure 8 shows

FIGURE 8
SELECTED FEDERAL PARTNERSHIPS WITH INDUSTRY



Years shown are fiscal years (e.g. FY1995 =1 October 1994 to 30 September 1995).

Source: Department of Commerce data, 1995.

the rapid growth of funding for these programmes in recent years. The Fiscal Year 1995 figures reflect Clinton Administration budget estimates, not actual appropriations.

The results of the mid-term elections in November 1994 brought brisk challenges to President Clinton's policies. The new Republican majorities in the House and Senate proposed rolling back the new technologically intensive public-private programmes, characterized as an 'industrial policy' which entailed too much funding and too extensive governmental intervention in the market. This debate has attracted growing attention, but many companies have not spoken out one way or the other.

Changes in companies

Companies are adapting rapidly to enormous changes in their regulatory and business environments. In turn, these changes affect how corporate management views R&D. Three of the most notable forces on business are mergers, governmental action and market changes driven by technological advance.

Mergers between large companies tend to reduce total R&D. A merger of roughly equal-size companies may result in doubled sales, but the resulting corporate R&D may increase by a factor of only 1.5 as overlapping programmes are reduced. In some cases the need for entire laboratories may cease; for example, the General Electric-RCA merger resulted in the sale of the David Sarnoff Research Center, which now performs contract research for many companies as a unit of SRI International.

Governmental actions sometimes have substantial repercussions on industrial laboratories. Perhaps best known is the American Telephone and Telegraph divestiture under US anti-trust laws. This action changed the Bell Telephone Laboratories, with a general downsizing and by reducing its emphasis on long-term research. Another result was the creation of Bellcore to perform R&D for the seven Bell regional operating companies. Further changes are underway.

Market changes driven by technological advance also have sweeping effects on company R&D. For example, as new trends in computer hardware and software took hold and many new competitors seized large market shares, IBM cut back the size, narrowed the range and shortened the time-horizon of much of its research.

Value of R&D to companies and stockholders

Top managements of companies view R&D differently from their predecessors a generation ago. No longer do top managers provide R&D funding based on a general faith in the payoff from research, or even because of a large demonstrated return on investment in R&D in their own company in the past. Studies showing large social rates of return on academic research or enhanced stock values due to successful R&D programmes are no longer persuasive.

Some trends suggest that the stock market's evaluation of intangible capital resulting from R&D declined in the USA during the 1980s. Relative to tangible capital, the value of R&D capital apparently declined by a factor of as much as three during the decade. This decline, if it is in fact real, could be due to several causes: for instance, an increase in the depreciation rate for R&D capital (this is consistent with decreasing product life cycles); or a fall in the private rate of return for R&D; or increased uncertainty in the benefits from R&D.

However, other evidence indicates that the value of a company's stock is enhanced if the growth in sales resulting from R&D is sufficiently greater than the cost of the research. This approach permits the programming of a 'correct' level of R&D for a particular company, with the critical variable being the productivity of R&D. The magnitude of this correct level depends in most cases on the industry in which the company is competing; for example, semiconductor and pharmaceutical firms may require more annual R&D per unit of sales to stay globally competitive than do firms in the steel industry.

More valuable than aggregate economic indicators are case studies at the level of each firm. Many companies find that the pattern of actual sales makes the case for R&D more compelling than national or industry-wide economic analyses. It is not unusual, for instance, for a company to have more than half its sales in products that were not in its inventory a decade earlier.

Search to research ratio

Today, chief executive officers and non-technical managers are more involved than in the past in developing the corporation's technology strategy and then measuring the results from those R&D investments. Sophisticated information technology makes monitoring possible. At the same time, industrial R&D organizations have flatter structures, i.e. decisions are pushed down to the lowest possible level because shortened product cycles demand flexibility and accountability. Thus, the authority of mid-level research managers has been eroded both from above and below.

The traditional vertical integration within companies, in technology as well as in business units, has given way in many cases to a new form of integration of technological competence through corporate alliances, where the partners are often international. Furthermore, in any company's laboratory, the scientists and engineers ('knowledge-providers' may be a better description) are shifting from full-time roles in research to a combination of both in-house research *and* a search for pertinent knowledge outside the firm. Company resources are also shifting towards greater emphasis on this external reconnaissance as the overall 'search to research' ratio is increasing.

It is important to understand the character of corporate alliances within and across industries. As firms chart their futures, a key distinction concerns strategic necessities versus strategic differentiators. Strategic necessities are the capabilities that all companies need to meet minimum competitive standards in a particular line of business. Companies are cooperating with each other to develop and maintain these strategic necessities through alliances, consortia and joint ventures. Substantial benefits may emerge from such cooperation, and substantial penalties may be paid for swimming against the tide on a technological solution to a common problem. Strategic differentiators are another matter. They provide distinctive competitive advantages in the market, and are the basis of intense competition between companies. Technological superiority is often a necessary (but not sufficient) condition for maintaining lasting strategic differentiation.

The future

Spending by US companies on R&D in the 1990s has been flat. A survey by the US-based Industrial Research Institute (IRI) indicated guarded optimism that 1995 will show higher R&D spending than 1994, but not by much. The 1992 NSF survey showed a large increase in industrial R&D in the late 1980s, as well as large increases in research and overall R&D in the service sector. However, a detailed explanation of these data is not yet available and most research executives, along with earlier surveys of IRI member companies, suggest that company support of R&D has not grown substantially since the mid-1980s.

Acquiring and applying new knowledge in the 1990s is much more than merely funding R&D. No company, no matter how large and powerful, can produce in its own laboratories all the new knowledge its businesses require. Companies search broadly for market-relevant and product-or-service-pertinent knowledge as well as performing research to develop knowledge in their own laboratories. Firms must run faster than their competitors: this means pressure to shorten product cycles, and they must innovate smarter and faster and obtain new knowledge efficiently. R&D is an expenditure, not just an investment, in the minds of company managers. Accordingly, great pressure has been exerted from the top of companies in the USA to increase R&D productivity substantially.

What does the future hold? Company-funded R&D and related 'search' activities are likely to increase over the next decade in real terms. Although further increases in the productivity of 'search and research' can be expected, the easy advances have already been made. This implies that increases in funding and personnel may be on the horizon. Whether this will prove to be a one-year or five-year horizon is hard to tell.

INTERNATIONAL COOPERATION

Perspectives on international cooperation may be grouped into three clusters. One concerns global institutions – i.e. changing requirements for, and rising problems with, cooperative research in many areas of science, engineering and medicine affecting every nation and field. A second concerns the needs and actions of individual North American countries, reflecting their distinctive national goals. Third are regional efforts among the three countries, based upon proximity, mutual scientific interests and a variety of political, social and economic incentives.

General outlook

Like scientists in all nations, North American professionals are internationally minded – participating in meetings and joint experiments, scanning the research literature, considering competitors and colleagues everywhere. But frustration grows about many of the mechanisms of international cooperation in science, engineering and medicine. Economic competition, with its technological foundation, produces some of the frustration because of new tendencies to consider tight restraints on communication of research results whenever commercial stakes may be at risk. Moreover, the international institutions that facilitate cooperation face new demands, vie for scarce funds and thus need renewal. *Ad hoc* arrangements have emerged to orchestrate large-scale global research in areas ranging from high-energy physics and fusion to AIDS and the human genome. The rising imperative to share costs, even in 'little science', makes cooperation more essential and management more complex.

For the future, reappraisals of the international infrastructure of cooperation must be conducted in two ways. One is a 'bottom up' mode – i.e. consulting younger and mid-level working scientists, engineers and research-oriented physicians about opportunities and needs. The second is a 'top down' perspective, i.e. involving senior leaders from government, universities and industry who know the strengths and weaknesses of the traditional ongoing system and can relate long-term public and private sector objectives to the roles for S&T. The underlying goal will be to chart those institutional reforms that help to energize national, regional and global development.

The criteria for choice in these reappraisals are more complicated now than a decade ago. For example, since electronic communications are such a powerful new tool for cooperation, the need for centralized staff coordination has changed and perhaps diminished. At the same time, new needs have arisen for jointly planning and financing major projects as well as for conducting global coordination of the collection, interpretation and dissemination of large databases. With generous public funding no longer assured, new frameworks may be required to ensure adequate quality-control, efficiency, reliability, participation and productivity in a far-reaching array of research investments for the next century.

The complex challenges are illustrated vividly in the environmental domain. With the global expansion of research in environmental sciences, rising investments in science must be related to tangible improvements in policies to upgrade environmental quality without sacrificing prospects for economic growth. From risk assessment at the local level to research coordination on national and international scales, each country aims to advance its own scientific knowledge and to learn how to apply the best data from global research to understanding environmental policy choices.

In the USA part of the interest in broadening international cooperation springs from the painful fact that the USA no longer can afford to finance alone the 'big science' projects that are at the frontiers of key fields, especially in the physical and engineering sciences such as fusion. Projects like these cost hundreds of millions of dollars – indeed, often billions – and require sustained, complex work over a decade or more. Governmental support involves the Department of Energy, NASA and the NSF. Several have been terminated owing to complex political and financial problems including, in some cases, large cost increases. For the future, international cooperation will be essential for such projects and must encompass plans, design, finance and management.

Regional trends

While no reliable surveys are available, informed estimates suggest that there are thousands of substantial contacts every year among working scientists, engineers and research physicians in Canada, Mexico and the USA. Many are focused on 'little science', i.e. in the traditional mode of sharing information and techniques within the research community. Many ongoing links are being facilitated by new trilateral activity symbolized by economic agreements such as NAFTA. Still more are fostered by electronic communications. At the same time, however, rising economic competition by the three nations in global markets may mean that some opportunities for R&D cooperation will be examined more closely to assure their commercial benefits.

Among the formal structures for North American scientific collaboration is the trilateral arrangement of the US National Science Foundation with Mexico's CONACYT and Canada's National Science and Engineering Research Council. Trilateral cooperation is also pursued through many specific *ad hoc* projects ranging from studies of migratory birds to work on food and drug standards. Undergraduate and graduate students move freely across boundaries, and although current budgetary cutbacks in all three countries will undoubtedly constrict the international flow of students and young investigators, the long-term trend will probably continue to be towards greater exchanges. The USA is likely to continue to be the largest scientific partner.

During 1993-94 Mexico affirmed a commitment to bringing its R&D investment up to 1% of GDP by the year 2000. Despite recent economic turmoil, Mexico will probably move towards this goal again as soon as circumstances permit. Such rising R&D would build the capacity for regional research efforts with Canada and the USA. Furthermore, North American S&T cooperation is likely to expand to the Asia-Pacific region and to parts of the western hemisphere.

Megascience cooperation

Megascience refers to very large, predominantly basic scientific research projects or programmes. The two major types of megaprojects concern central and distributed facilities. A detailed treatment of megascience at the global level is given in the chapter devoted to the subject later in this *Report*.

The USA and Canada have been and are currently involved in the construction and operation of central facility megaprojects. Scientists from those countries and from Mexico have also participated as 'users' of central facility megaprojects located in other countries and as researchers in distributed megaprojects. Both kinds of megaproject are of crucial importance to the advancement of certain fields of science and to the solution of basic problems facing the world community, such as global climate change.

The availability of funding for megaproject construction is increasingly scarce in Canada and the USA. The cancellation of the Superconducting Super Collider (SSC) in the USA and the demise of the KAON project in Canada amply demonstrate this. One bright spot is the ongoing construction of the Gemini telescopes, with Canada and the USA (along with the UK) serving as partners.

Data handling is perhaps the most pressing issue among sponsors of distributed facility megaprojects. In addition to the fundamental questions of the costs and effectiveness of data collection, storage and distribution, important problems must be addressed about standards for data quality and the conditions (including costs) for making data available to researchers worldwide.

The enhanced capabilities and low costs of modern communications have also affected the debate over institutional arrangements for funding and managing megaprojects. To some extent, in 'small science' the need for institutions to coordinate and catalyse international cooperation is disappearing. But in megascience the 'bottom up' process of scientific consultations can address only the easy parts of the problem: issues of scientific merit and feasibility. Questions of scientific priority and financial affordability are different, and resolving these issues demands governmental decisions and institutions building both public and private support. The future for international science institutions may very well be the appearance of strong new ones for megascience and radical restructuring of institutions involved in 'small science' cooperation.

DEFENCE RESEARCH AND DEVELOPMENT

Within the North American region, defence R&D programmes are much more significant in the USA than in either Canada or Mexico. Accordingly most of this section concerns US trends.

Defence policy and funding

US defence spending is down and still declining; since 1985 the defence budget has decreased more than 40% in real terms. These cuts, and the related consolidation of defence firms through mergers and acquisitions, have eliminated more than a million jobs since 1987. Further reductions in spending and substantial job losses are projected for the rest of the 1990s.

Since most of the defence companies and their suppliers are involved in high-tech products and services, the net effect on private sector research and development is severe. Governmental laboratories and universities also continue to experience sharp reductions in their defence funding for R&D. Broadly put, the physical and engineering sciences, mathematics and computer science are the fields most affected.

Reaching more than 50% of the federal government's total funding of *basic* research during the 1950s, the defence proportion dropped to roughly 25% during the 1960s. It fell further to about 10% during the 1970s and 1980s as the National Institutes of Health and other agencies assumed larger shares in US research. Defence R&D declined from about 20% of the national R&D investment on campuses to less than 5% in the 1980s and early 1990s.

As funding has changed, so has the focus of debate on overall defence R&D. During the past decade, concerns were raised about the substance of key projects, such as whether strategic ballistic missile defence would be either technically feasible or consistent with prudent arms control and national security policies. By the mid-1990s many debates concentrated more on the philosophy and goals of sustaining 'dual-use' R&D, i.e. publicly funded efforts combining military and civilian purposes, such as in the Technology Reinvestment Project. More broadly, new worries have arisen about financing the long-term preservation of the S&T base for US defence programmes as the US Congress considers deep cuts in funding for defence-related work on campuses.

Table 7 summarizes the recent R&D funding by the US Department of Defense. The top two lines – often combined in the phrase 'technology base' – constitute the basic and applied science activities which are the principal source of funds for academic investigators. This base of about US$4 billion, especially the support of 'basic research', has been relatively stable in the past, but is presently under heavy pressure.

Table 8 compares defence and other US federal

TABLE 7
DEFENCE R&D FUNDING IN USA, 1994-95

	FY 1994 (actual)	FY 1995 (est.)
	(US$ billions)	
Basic research	1.2	1.2
Exploratory development	2.7	3.0
Advanced technology	6.2	4.3
Demonstration/validation	2.7	4.3
Engineering and manufacturing development	7.3	8.9
Management support	3.4	3.4
Operational system development	11.2	10.2
Total	34.6[1]	35.4[1]

1. Numbers may not add up to total owing to rounding and adjustments.

Source: Defense Department and AAAS data.

TABLE 8
DISTRIBUTION OF US FEDERAL R&D, 1995

Function	% total R&D	% basic research
Defence	55	9
Health	16	44
Space	11	12
Energy	4	7
General science	4	19
Other (including environment and agriculture)	10	9

Source: NSF data, 1995.

TABLE 9
ALL R&D AND R&D FACILITIES BY SELECTED US GOVERNMENTAL COMPONENTS, 1980-94

	FY 1980	FY 1994
	(constant FY 1987 US$ billions)	
Defence	21.8	30.3
Space	6.8	6.6
Health	6.0	9.2
Energy	6.0	2.5
General science	2.0	2.5
Natural resources/ environment	1.4	1.7

Sources: AAAS data, 1994 and 1995.

TABLE 10
US DEFENCE SCIENCE AND TECHNOLOGY STRATEGY AND PRIORITIES (SEPTEMBER 1994)

Guiding principles
1. Develop transition technology for warfighting needs
2. Reduce cost
3. Strengthen the commercial-military industrial base
4. Promote basic research
5. Assure quality

Technology priorities on defence-wide basis
1. Information science and technology
2. Modelling and simulation
3. Sensors

Army priorities: Terrestrial science and armour materials
Navy priorities: Ocean geophysics and acoustic signature analysis
Air Force priorities: Atmospheric physics and space launch

Source: US Department of Defense, 1994.

functions for 1995 in terms of per cent total R&D and per cent basic research. Table 9 reviews the 1980 and 1994 funds for R&D (and related facilities) by defence and other major governmental components.

US priorities for defence S&T

In September 1994 the US Department of Defense issued two major reports, a *Science and Technology Strategy* and a *Technology Plan*. Table 10 illustrates key components of the strategy. Such plans change each year as budgets and R&D results unfold. Nonetheless, these policy outlooks are likely to be sustained during the mid-1990s.

Although during the 1980s and early 1990s the US Defense Department renewed its emphasis on basic research, funding for this purpose is likely to be reduced in the short term, as it was during 1995. To the extent that defence research funding declines, universities will be affected because most defence basic research is carried out on campuses. In 1994 the Pentagon provided about US$1.5 billion of the total federal R&D funding of about US$11.6 billion to on-campus research. Nearly half of all federal support for mathematics and computer science at universities, and more than 40% of support for engineering research, came from the Defense Department. Both the stability of such funding and its distribution among key fields are likely to be critical subjects for decisions in US S&T policy during 1995-96.

Detailed objectives, funding and timetables for 19 defence technological areas were also announced in late 1994. These priority technologies include aerospace propulsion, chemical and biological defence, many applications of advanced electronics and modelling and simulation. The efforts involve tens of billions of dollars in exploratory development, advanced development and engineering models over a number of years. Although most of this work is carried out in industry, the underlying scientific base involves both governmental laboratories and universities. The in-house laboratories of the Department of Defense are also being re-evaluated and trimmed along with other defence programmes.

US trends in DOE's national laboratories

The USA has long had a group of 'national laboratories' affiliated with the Department of Energy. These multi-purpose laboratories focus not only on nuclear weapons but also on a broad array of fields related to energy, waste management, materials engineering, biomedical devices and environmental goals. Several have had strongly defence-related missions. Just three – Los Alamos, Lawrence Livermore and Sandia – have combined funding of almost US$3 billion and a total of 20 000 staff.

As weapons work has declined – one estimate is from more than 60% to about 40% of their budgets – these laboratories try to diversify. The goals are to engage new sponsors and to expand links with firms and universities that are more closely coupled with civilian purposes and markets. Because the laboratories have great talent and distinguished traditions, changes so far have been cautious. The shake-out will take several years. But jobs will be cut as budgets fall and as experimental arrangements for new missions lead to more or less successful transitions into fields such as environmental S&T.

An independent task force recently reviewed 'alternative futures' for the Department of Energy laboratories. The group concluded that the labs have not yet developed sound new missions and that their governmental governance does not work well. The US government faces many decisions about how to proceed, especially since some informed observers recommend cuts of as much as 50% in the laboratories.

Canada and Mexico

Canadian R&D expenditure on defence was about US$250 million during 1993-94, and is not likely to rise substantially in the light of the overall constraints on the Canadian budget. The number of federal personnel engaged in Canadian defence S&T dropped slightly during 1991-94. Canada continues to be a key participant in NATO defence efforts, including a variety of peacekeeping and military-diplomatic plans involving advanced technology. Mexico, in contrast, has only a small defence programme and invests in little military R&D.

PUBLIC ATTITUDES AND NATIONAL MOODS

Public support for S&T is widespread. This support is expressed, for example, through the political process of debate on government R&D funding. National regulatory and tax structures also tend to favour science and education, especially in the USA. Beyond these specific, financially oriented themes, however, extensive survey data available in the USA reveal mixed and changing national moods.

The good news

American adults generally hold a positive attitude towards S&T, and have done so for a long time. Time-series data show this attitude becoming slightly more supportive of science over the past decade. Positive attitudes toward science are correlated directly with the level of formal education and inversely with age. Younger, college educated individuals have the most confidence in science. Survey data from 1993 demonstrate the strong correlation between the level of education and a favourable assessment of the benefits (as compared to the harms) of scientific research.

Mixed views of research and scientists

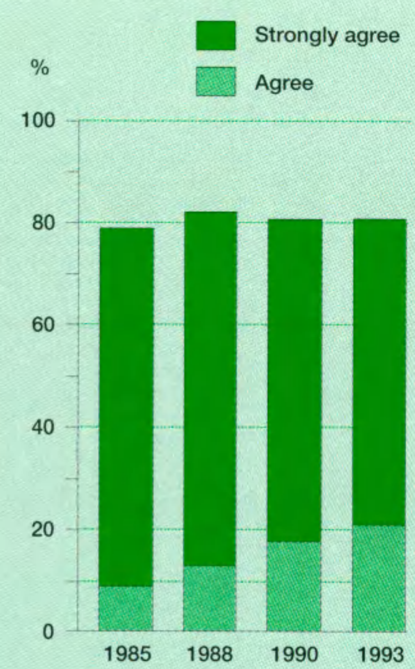
The US public ascribes good motives to scientists, with about 80% of those surveyed agreeing with the proposition that scientists want to work on things to make life better.

On the other hand, the same 1993 survey showed that over half of the American public feels that many scientists make up or falsify research results when it is in their own interests to do so. This confirms the fears of many scientists that unless the issue of integrity is dealt with head-on, the public's confidence in organized science will be undermined and public funding for science will be jeopardized. Another lingering public concern relates to the use of animals (especially mammals) in research. On this issue the public is almost evenly split, with a bare majority favouring the use of mammals such as dogs in biomedical research. Such divisive issues reinforce what many observers see as a small, but growing 'anti-science' movement that undercuts confidence about science itself and about the ability of science-based programmes to advance social and economic goals.

Approval of government support of research

The USA has a tradition of supporting R&D for practical purposes in both the public and the private sectors, which is reflected in the R&D budgets of

FIGURE 9
ATTITUDES TOWARDS FEDERAL SUPPORT FOR BASIC SCIENTIFIC RESEARCH, 1985-93



Question: 'Even if it brings no immediate benefits, scientific research which advances the frontiers of knowledge is necessary and should be supported by the federal government. Do you strongly agree, agree, disagree, or strongly disagree?'

agencies responsible for defence, energy and health. Only since the Second World War has the federal government supported basic research on such a large scale. There remains a consensus that this is an important federal responsibility, with approval levels running consistently at 80%. Four surveys taken from 1985 to 1994, however, indicate a troubling trend: although the 80% approval level holds, Figure 9 shows the percentage of those who 'strongly agree' that basic research should receive federal support declining by over 10 percentage points. The drive to reduce government deficits, along with caustic attacks on the role and impacts of science in society, combine to make the US national mood more cautious about investments in research.

CONCLUDING NOTE

Science budgets in North America are tight, private firms invest cautiously in R&D and academic research is under siege. Variations on these cross-currents are evident in Canada, Mexico and the USA.

With caps on funding for science and engineering likely to be prolonged, the North American governments are conducting high-level reviews of research priorities. Major institutional changes may unfold as governments struggle to finance basic science and frame new policies that will spur national job creation and economic growth. Especially in the USA, powerful forces aim to reduce government spending and this process will undoubtedly affect R&D. The purposes, scale and scope of public-private partnerships related to R&D-intensive commercial markets are being hotly debated.

The scientific community has not yet adjusted to these conflicting demands. Nonetheless, the opportunities are great in many fields, and the needs for advancing S&T are crucial for meeting most social and economic goals. Accordingly, the latter half of the 1990s may well see increased R&D investments, if not by the public sector then by the private sector.

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Latin America

GUILLERMO CARDOZA AND RAIMUNDO VILLEGAS

Our contribution to the *World Science Report 1993* presented a historical overview of the evolution of scientific research in Latin America from the colonial period to the present, including a brief description of the structure of the science and technology (S&T) sector in the countries of the region. It also included a global review of the state of science, using as indicators the number of scientists and research units in the various fields, expenditure, scientific production and regional and international scientific cooperation. Certain suggestions were also made of ways to strengthen the national S&T sector and to promote regional scientific cooperation (Villegas and Cardoza, 1993).

This chapter deals with important aspects of the S&T sector in the light of the current situation in Latin America. First, a picture of the status of science is presented and, as far as available information has allowed, previous statistics on S&T have been enriched with additional data. Indicators of economic development are also included, as a contribution to the discussion on the role that science must play in the creation of a new S&T-supported development model.

Further issues considered important for the progress of science in Latin America are then discussed. They are: the establishment of priorities for the financing of S&T; the relationship between education and S&T, with special emphasis on recruiting human resources for S&T; the evaluation of scientific cooperation in Latin America with mention of some major regional initiatives; and the role of new telecommunication technologies in S&T cooperation. Finally, the status of S&T in Latin America is considered within the context of the economic crisis that has affected the countries of the region since the beginning of the 1980s.

Since efforts made by scientists have had only moderate impact in most Latin American countries, it would appear necessary to harmonize S&T and industrialization policies, in order to ensure that S&T contributes to the process of industrial modernization, a prerequisite of the economic growth required to reduce poverty and integrate the majority of the population into the development process. Similar consideration could also be given to other sectors having a significant S&T component, such as health, agriculture, environment and energy.

In order to illustrate the difference that the harmonization of S&T policy with other national policies could mean for Latin America, a comparison is made between the situations of Argentina, Brazil, Chile, Mexico and Venezuela, the five Latin American countries with the highest scientific production, and the Republic of Korea, Singapore and Chinese Taipei, three of the newly industrialized countries (or NICs) of Asia.

STATUS OF SCIENCE IN LATIN AMERICA

Tables 1 and 2 present indicators for education, science and economic development in Latin America for the years 1980 and 1990. The purpose of presenting these data is to study their variations and possible relationships. Table 1 shows figures for the total population, the number of students enrolled in higher education, research and development (R&D) personnel and the number of scientific publications produced in the countries of Latin America. Table 2 depicts the values corresponding to the gross domestic product (GDP), GDP per capita, inflation rate, gross domestic investment (GDI) and expenditure on education and R&D as a percentage of GDP. This kind of comparative study is difficult because of the lack of efficient national S&T statistical systems.

Table 1 reveals a large increase in the number of students in higher education per 100 000 inhabitants for the majority of the countries of the region between 1980 and 1990, this increase being greater in Argentina, Bolivia, Colombia, Chile, Cuba, El Salvador, Honduras, Uruguay and Venezuela. A decrease is observed in Brazil, Ecuador, Nicaragua and Paraguay. However, as indicated by UNESCO (1995), the quantitative expansion of higher education in

TABLE 1
SCIENCE AND HIGHER EDUCATION IN LATIN AMERICA

	Population (millions)		Tertiary-level students (per 100 000 inhabitants)		R&D personnel (per million inhabitants)		Scientific publications (per million inhabitants)	
Country/sub-region	1980	1990	1980	1990	1980[1]	1990[1]	1980	1990
Mexico	69.6	86.1	1 387	1 552	194 (84)	260 (91)	15.8	15.7
Central America								
Costa Rica	2.2	3.0	2 434	2 461	145 (79)	538 (89)	42.2	29.0
El Salvador	4.5	5.1	372	1 512	123 (81)	28 (89)	–	1.2
Guatemala	6.9	9.2	736	–	53 (74)	219	6.1	3.6
Honduras	3.7	5.1	705	854	–	138	3.0	1.6
Nicaragua	2.7	3.8	1 259	836	197 (85)	207 (87)	0.4	1.3
Panama	1.9	2.4	2 064	2 181	120 (75)	354	5.3	38.3
Caribbean								
Cuba	9.7	10.6	1 568	2 285	553	1 205 (89)	6.3	13.9
Dominican Republic	5.4	7.1	–	–	–	70	2.0	2.7
Andean								
Bolivia	5.6	7.4	1 494	1 975	–	137 (86)	4.3	3.8
Colombia	25.9	32.3	1 024	1 496	139 (81)	138	4.3	5.8
Ecuador	8.1	10.2	3 321	1 950	194 (79)	84 (84)	1.7	3.9
Peru	17.3	21.5	1 771	3 450	530	–	4.3	6.6
Venezuela	15.0	19.3	2 044	2 847	279 (83)	284 (89)	29.4	22.0
Brazil	121.2	150.3	1 162	1 074	298 (83)	432	17.3	19.8
South Cone								
Argentina	28.2	32.3	1 741	3 293	337	352 (88)	46.5	60.4
Chile	11.1	13.1	1 305	1 938	320 (81)	422	98.4	83.8
Paraguay	3.1	4.2	855	769	–	–	0.5	11.9
Uruguay	2.9	3.1	1 338	2 315	–	675	15.5	25.2

1. If different, the year of the data is given in parentheses.

Sources: ACAL, 1994; ISI, 1980 and 1990; UNESCO, 1993 and 1994; World Bank, 1992*a*.

most countries was unfortunately not matched by a growth in quality and relevance. Likewise, the increase in the number of students was not accompanied by a proportional increase in S&T teachers.

In Table 1 the data on R&D personnel per million inhabitants also reveal growth in the majority of the countries for which that information is available. For some countries the data available correspond to years close to 1980 and 1990, which were normalized according to the population of the corresponding year (in parentheses). Significant increases can be observed in Argentina, Brazil, Costa Rica, Cuba, Chile, Guatemala, Mexico, Panama and Venezuela, and reductions in Ecuador and El Salvador. The apparent

TABLE 2

EXPENDITURE ON SCIENCE AND EDUCATION AND MACROECONOMIC VARIABLES OF THE LATIN AMERICAN COUNTRIES

Country/sub-region	GDP[1] 1988 (US$ millions) 1982	GDP[1] 1988 (US$ millions) 1990	GDP per capita (1988 US$) 1982	GDP per capita (1988 US$) 1990	Inflation average annual rate (%) 1980-91	GDI[2] average annual growth rate (%) 1980-90	Education expenditure as % of GDP 1980	Education expenditure as % of GDP 1990	R&D expenditure as % of GDP 1980[3]	R&D expenditure as % of GDP 1990[3]
Mexico	169 170	184 080	2 498	2 266	66.5	–2.0	4.7	4.1	0.43	0.30
Central America										
Costa Rica	3 674	5 081	1 517	1 685	22.9	0.7	7.8	4.6	0.14 (86)	0.16
El Salvador	4 771	5 477	1 032	1 043	14.4	–0.6	3.9	1.8	–	0.90 (89)
Guatemala	7 376	8 290	1 008	901	15.9	–1.4	1.9	1.4	0.50 (83)	0.20 (88)
Honduras	3 103	3 915	788	762	6.8	0.4	3.2	4.6	–	–
Nicaragua	2 517	1 961	851	506	583.7	–3.7	3.4	–	0.37 (85)	–
Panama	4 851	4 742	2 374	1 961	2.4	–2.8	4.9	5.5	–	0.40
Caribbean										
Cuba	–	–					7.2	6.6	–	0.80
Dominican Republic	4 324	4 856	723	677	24.5	0.2	2.2	–	–	–
Andean										
Bolivia	6 280	6 525	1 069	892	263.4	–6.2	4.4	3.0	–	–
Colombia	34 365	46 989	1 224	1 425	25.0	0.9	1.9	2.9	0.10 (82)	0.60
Ecuador	11 790	13 336	1 370	1 260	38.0	–4.2	5.6	2.8	0.13 (79)	0.11 (89)
Peru	34 001	29 083	1 883	1 350	287.3	–5.2	3.1	–	0.20 (84)	–
Venezuela	61 865	65 027	3 881	3 295	21.2	–7.0	4.4	4.1	0.35 (84)	0.37
Brazil	275 689	333 162	2 173	2 216	327.6	2.2	3.6	4.6	0.44	0.66
South Cone										
Argentina	87 241	86 355	2 999	2 672	416.9	–7.0	3.6	–	0.77 (81)	0.80 (92)
Chile	23 571	33 289	2 046	2 527	20.5	0.6	4.6	3.7	0.44	0.55
Paraguay	5 278	6 659	1 572	1 557	25.1	1.2	1.5	–	0.16 (71)	0.03
Uruguay	7 653	8 539	2 593	2 760	64.4	–8.5	2.3	3.1	0.20 (75)	0.20 (87)

1. GDP: gross domestic product. 2. GDI: gross domestic investment. 3. If different, the year of the data is given in parentheses.

Sources: ACAL, 1994; IDB, 1992 and 1993; MCT, CNPq and IBICT, 1994; UNESCO, 1993 and 1994; World Bank, 1991*b* and 1993.

lack of correlation between the growth in R&D personnel and the number of scientific publications could be due, among other things, to the time delay usually necessary for personnel to become productive. An example of this might be seen in Venezuela, where the increase in personnel of 1990, not paralleled by a similar increase in publications in the same year, may nevertheless be the reason behind the growth in publications in 1993 (Figure 1). However, other factors, such as the creation of the system for the promotion of scientists in that country in 1990, could also explain the increase in publications in 1993. In other cases, a lack of correlation could be the result of differing systems of classification of R&D personnel.

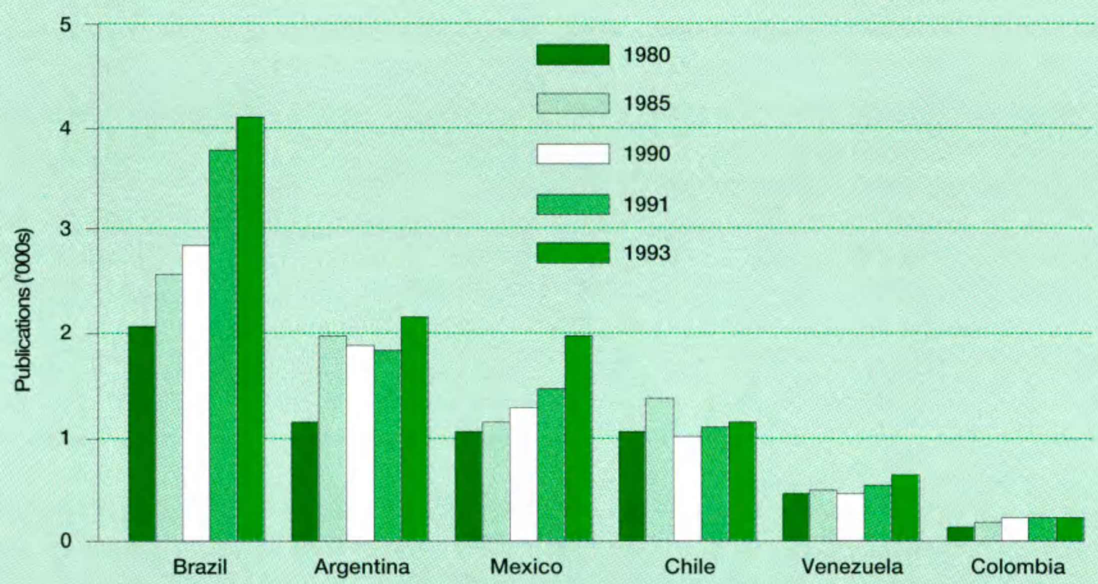
The number of scientific publications per million inhabitants, taken as an indicator of scientific production, increased significantly in 1990 compared with 1980 in Argentina, Cuba and Panama, and decreased in Costa Rica, Chile and Venezuela. The countries with the highest net number of publications in both years were: Argentina, Brazil, Chile, Colombia, Mexico and Venezuela. The data corresponding to these countries for the years 1980, 1985, 1990, 1991 and 1993 are shown in Figure 1. Of total numbers of scientific publications produced by Latin America in 1980 and 1990, 6 551 and 8 727 respectively, these six countries together contributed 94% and 91.5%, respectively.

Table 2 gives the data corresponding to expenditure on both education and R&D as a percentage of GDP for 1980 and 1990. The figures show that in eight countries (Bolivia, Chile, Costa Rica, Cuba, Ecuador, El Salvador, Guatemala, Mexico and Venezuela) out of 14 for which the data for both years were available, there was a remarkable decrease in expenditure on education. A similar reduction in R&D expenditure is observed in four countries (Guatemala, Ecuador, Mexico and Paraguay) out of 11 for which the data for both years were available. It is important to note that in no case did R&D expenditure reach 1% of GDP.

The reductions in education and R&D expenditure were due to the severe economic crisis that has affected the region since the beginning of the 1980s, and particularly to capital outflow related to foreign indebtedness. As demonstrated by Table 2, most of the

FIGURE 1

PUBLICATIONS OF THE SCIENCE COMMUNITIES IN BRAZIL, ARGENTINA, MEXICO, CHILE, VENEZUELA AND COLOMBIA



Sources: SCI, 1980, 1985, 1991, 1993.

Latin American countries registered significant reductions in per capita income and in GDI, and also suffered high inflation rates, even reaching levels of hyperinflation as occurred in Argentina, Bolivia, Brazil, Nicaragua and Peru. As a consequence of this economic situation and of the devaluation of the local currencies, budgets of research centres declined, affecting research salaries, the maintenance of the research infrastructure, and the acquisition of equipment and research material that for the most part must be imported. Some countries, however, have tried to mitigate the impact of the economic crisis through financial resources from multilateral organizations.

Priorities for the financing of S&T

In the decades that followed the Second World War, the countries of Latin America, with the support of UNESCO, established national councils for S&T that concentrated efforts on the creation of a scientific infrastructure, in the hope that scientific progress would be translated into development. However, the crisis that marked the 1980s clearly indicated that the production of knowledge alone does not lead spontaneously to development. As research activities were largely concentrated in the basic sciences, and were carried out in universities and research centres with the characteristics of graduate schools, the greatest impact was felt by the higher education system and to a much lesser extent by sectors such as health, agriculture and natural resources.

It has become clear that basic research, and even oriented basic research, require additional science policy decisions in order to guarantee their application in other sectors. Only exceptionally do the research results automatically impact on areas outside education and science itself. More recently, as these facts became apparent, governments, S&T councils, research institutions and private enterprises began to support the creation of R&D centres dedicated to applied research and/or development in areas of particular interest to their own countries. These centres quickly demonstrated the contribution that S&T could make to the solution of problems in various sectors.

The budgetary cutbacks in the S&T sector caused by the economic crisis of the 1980s and the demands of technological modernization posed by the restructuring of the economies of the region fuelled debate on the need to establish a system of research resource allocation which would take into account national development priorities. It is clear that it is necessary to bring together those responsible for development policies and the research community in order to design mechanisms to ensure optimal use of investments in research. Today, efforts should concentrate on the creation of channels for this dialogue so that research priorities do not overlook the intrinsic criteria of scientific endeavour. In this process, the participation of the political sector is essential to securing the resources required to promote priority basic and applied research and to guaranteeing both the norms that regulate the research and the successful pursuit of economic and social objectives.

Recruiting human resources for S&T

The shrinking enrolment in university degree programmes in science and engineering reported by several countries in the region is linked to the meagre science teaching at lower education levels, as well as to the lack of attraction of careers in research, particularly with regard to income, social recognition and professional stability. There is no current enthusiasm for these vocations.

It is very difficult nowadays to offer a growing population of undergraduate students, generated by the expansion of higher education during the last decades (Table 1), an adequate level of quality education. A similar trend is noted in graduate programmes in universities and research centres, although at this level the student population is still small. In undergraduate science programmes, the limiting factors are the recurrent budgetary cutbacks, the lack of trained staff and the growing number of part-time instructors replacing full-time staff, as well as the absence of educational activities geared to create an early attraction towards research careers. At the graduate level, in addition to the scarcity of good advisors and the limited research resources, the lack of recognition and support for high-quality basic and applied research tends to make science an unattractive professional career. All of these compromise the continuity of research projects, and the very existence of the S&T sector is at stake.

It has long been recognized that for the sciences and the arts to flourish, fertile ground must be prepared in advance. In this regard, the countries of the region need to face up to the dual challenge of expanding and including science education at all levels. This is the only way to generate the human resources needed to reach a more equitable S&T-based development.

Krauskopf (1995) underlines that since S&T capacity in Latin America is linked for the most part to universities, they must act institutionally in order to provide a serious and stable environment for critical reflection and the creative task. Certainly, universities and research centres need support in order to provide an adequate response to the demands imposed by the modernization of Latin America.

Governments need to redefine the role that universities and research centres are called upon to play in these times of great expectations and rapid transformations. Although this evaluation process is already under way in several countries of the region, the greatest danger lies in having the universities and basic research centres abandon their essential vocation of knowledge production in order to become primarily technical service providers. As Hasselgren and Nilsson (1990) indicate, the development of basic and applied scientific research activities in the universities is also fundamental in order to guarantee that the faculty '... should not only have the opportunity to follow and understand the latest developments and be able to relate them to the society where they live, but also that, through research, they must be able to teach scientific methodologies and approaches'. As indicated by Pavitt (1993), 'contrary to the common belief, the main economic benefit of basic research is not knowledge directly applicable in a narrow range of sectors, but background knowledge, research skills, instruments and methods that yield economic benefits over a much broader range of sectors'.

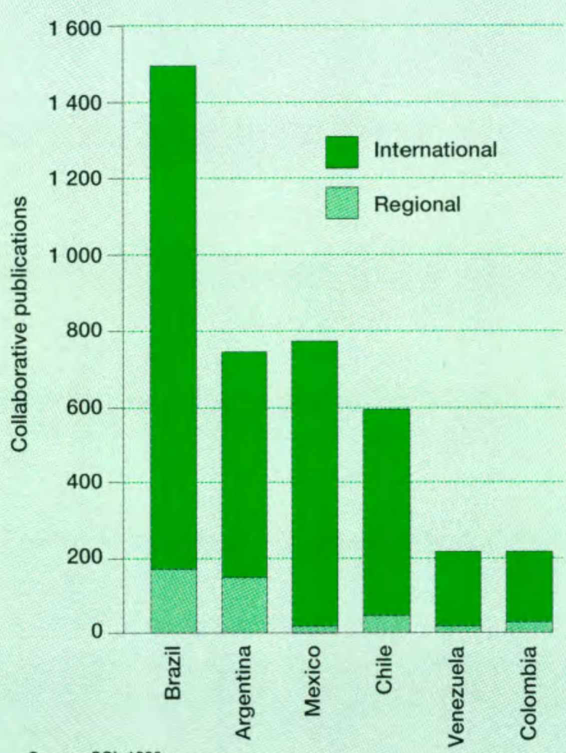
On the other hand, we must keep in mind in the formulation of staff training policies the migration of scientists and auxiliary R&D personnel to industrialized countries, and also the declining enrolment of students in science and engineering programmes which poses a problem of shrinking numbers of scientific personnel for some countries of the region. These trends are emphasized by the growing globalization of the labour market for scientists and high-level technical staff. Forecasts for the coming years indicate that industrialized countries will experience a growing shortage of such personnel (OECD, 1992). This situation obliges the countries of Latin America to provide competitive working conditions in order to curb the brain drain of scientists and technical staff. To this end, the highest priority is to train science teachers, update the study programmes, produce relevant teaching texts and provide educational institutions with adequate infrastructure. The region offers some good examples of how to pursue these urgent goals.

SCIENTIFIC COOPERATION IN LATIN AMERICA

As shown in Figure 2, Latin American scientists cooperate for the most part with scientists from industrialized countries and to a lesser degree with those of the same region. As in our 1993 report we have used the numbers of scientific publications produced jointly by scientists from two or more countries in Latin America as an indicator of regional cooperation, and the numbers of those produced by scientists from one or more countries of Latin America with scientists from countries outside the region as an indicator of international cooperation.

The relative scarcity of regional cooperation is considered to be largely due to the isolation caused by the difficulties of communication between Latin American scientists, and by the small number working on the same problem or related scientific topics. In addition, if we consider that graduate education programmes are relatively recent in these countries, it is easy to understand why most of the cooperation takes place with colleagues in industrialized countries, where most of the scientists have received their doctoral degrees or have worked as postdoctoral fellows for some time. As Hasselgren and Nilsson (1990) have pointed out, it also means that 'most Third World country scientists... have been engaged in research relevant to industrialized countries but not necessarily to their home countries'. These personal links and common research interests result in permanent relations that do permit scientists who have returned to their countries of origin to keep up to date in areas of frontier S&T and, in some cases, even to receive certain inputs and funding.

FIGURE 2
REGIONAL AND INTERNATIONAL COOPERATION UNDERTAKEN BY SCIENTISTS IN BRAZIL, ARGENTINA, MEXICO, CHILE, VENEZUELA AND COLOMBIA, 1990



Source: SCI, 1990.

In order to avoid the tendency for links with industrialized countries to lead to brain drain when local difficulties arise, it is essential that an adequate environment be offered for returning scientists. In addition, the national organizations in charge of S&T policy should define the areas in which human resources are needed and promote local graduate study programmes that cover them. Such programmes should be affiliated in some way to the major scientific centres of industrialized countries, ensuring a secure linkage between graduate students and the needs of their countries and region, as well as high quality local education.

At the same time, the establishment of links with Latin American scientists residing outside the region offers great potential for cooperation by providing access to areas of frontier research with channels for exchange and cooperation in joint projects.

Regional centres, networks and programmes for cooperation

During the past five decades, UNESCO has played a significant role in the promotion and development of S&T cooperation in Latin America, mainly through support for the creation of national research councils for S&T, regional centres for training and updating human resources, and other regional and national initiatives. In addition to UNESCO, other organizations have also promoted scientific activities in Latin America. Among these are the Organization of

American States (OAS), the International Council of Scientific Unions (ICSU), the Third World Academy of Sciences (TWAS) and the Programme of Science and Technology for Development (CYTED).

The regional centres created jointly by UNESCO and certain countries of the region took off in the late 1970s and early 1980s. Among the centres, we would like to mention the Latin American Centre of Physics (CLAF), the Latin American Centre for Biological Sciences (CLAB), the International Centre of Tropical Ecology (CIET) and the Simon Bolivar International Centre for Scientific Cooperation (CICCSB), the first with headquarters in Brazil and the other three in Venezuela. These centres offer short intensive courses and workshops that have helped to promote the personal acquaintance of many scientists in Latin America interested in related research topics. Other centres of an international character supported by other organizations are the Central American Institute of Research and Industrial Technology (ICAITI) and the Institute of Nutrition of Central America and Panama (INCAP) both located in Guatemala, the Inter-American Institute for Cooperation on Agriculture (IICA) with headquarters in Costa Rica, the International Potato Centre (CIP) in Peru, and the International Centre of Tropical Agriculture (CIAT) and the International Centre of Physics (CIF) both located in Colombia.

Also worthy of note is the creation of networks, pioneered by the Latin American Network of Biological Sciences (RELAB) with headquarters in Chile, which was created in 1975 under the sponsorship of the United Nations Development Programme (UNDP) and UNESCO. Presently it has 14 national members (Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Ecuador, Honduras, Mexico, Paraguay, Peru, Uruguay and Venezuela) and six regional members comprising the Latin American Associations for Biochemistry and Molecular Biology (PABMB), Botany (ALB), Cell Biology (SIABC), Genetics (ALAG), Pharmacology (ALF) and Physiological Sciences (ALACF), and is sponsored by ICSU, UNESCO and OAS. RELAB pursues the integration of regional activities and policies of research and training in the biological sciences. Among its activities are the preparation of studies of different factors that affect biological research and training in the region and the organization of symposia, workshops and training courses. RELAB is now part of the Committee on Science and Technology in Developing Countries – International Biosciences Networks (COSTED/IBN), a joint initiative of ICSU and UNESCO established to organize similar networks in chemistry, mathematics, physics, earth sciences and astronomy. The Latin American Academy of Sciences (ACAL) is also participating in the organization of these thematic networks.

Other networks devoted to specific research areas, such as the Regional Programme of Biotechnology for Latin America and the Caribbean (PRB) with headquarters in Argentina, the Latin American Network of Botany (RLB) located in Chile and the High Altitude Andean Biology Research Programme with headquarters in Peru, also support research projects and training courses. The International Brain Research Organization (IBRO) has two branches in Latin America, CARIBRO with headquarters in Cuba and SABRO in Chile.

At the sub-regional level it is worth citing, as examples, the S&T Programme of the Andres Bello Agreement Executive Secretariat (SECAB) located in Colombia, established by the Andean countries to strengthen cooperation in science, education and culture; the S&T Programme of the Andean Simon Bolivar University located in Bolivia, which promotes exchange of information in the fields of biotechnology, new materials, information technologies and energy, and the Argentinean-Brazilian Centre for Biotechnology (CABBIO), which coordinates binational research projects.

One singular initiative to promote S&T and industry cooperation at the regional level is the Bolivar Programme launched by Venezuela and supported by the Interamerican Development Bank (IDB). This programme promotes joint ventures between R&D centres and enterprises located in various Latin American countries.

ROLE OF NEW TELECOMMUNICATION TECHNOLOGIES IN S&T COOPERATION

The new telecommunication technologies, offering both high speed and low cost, are facilitating information flow and the setting up of cooperation networks in S&T, allowing for groups of scientists living in different countries to maintain an exchange of information in work areas of common interest.

Many applications have been developed in the context of these telematic networks. A few examples are: e-mail; access to bibliographic and documentary data banks; the use of remote processing capacity; and the creation of discussion groups on specific topics. These networks also offer the possibility of creating information systems to support research tasks and the diffusion of technology. They quite clearly represent a powerful instrument available to the international S&T community and could be channeled towards the creation of a global electronic scientific society.

Computer-based communications also become a very useful tool in reducing the isolation of scientists in developing countries (Cardoza, 1993). Communications that are established in the first instance at the personal level can eventually lead to the development of formal inter-institutional cooperation agreements.

These telecommunication technologies will also facilitate the setting up of linkage programmes between scientists in Latin America and their colleagues who have left to take up residence in the industrialized countries. In this way we can begin to give substance to the concept of the global scientific community of Latin America previously envisaged (Villegas and Cardoza, 1993), and a programme of international scientific cooperation involving expatriate scientists in the development of science in their native countries and in the region.

THE ECONOMIC CRISIS AND ITS IMPACT ON S&T AND EDUCATION

The legacy of the crisis of the 1980s has conditioned later development in the countries of Latin America. During that decade, as shown in Table 2, the decline in the standard of living of the population was coupled with an inflationary process and with a reduction of investments able to generate productive

Regional cooperation and ACAL

The Latin American Academy of Sciences (ACAL) is a regional scientific society with headquarters in Venezuela, sponsored by the private Simon Bolivar Foundation for the Latin American Academy of Sciences (FSB-ACAL). The membership of the Academy now consists of 120 scientists from Argentina, Brazil, Colombia, Costa Rica, Chile, Ecuador, Mexico, Peru, Uruguay and Venezuela, and is electing new fellows from the same and other countries to increase its membership to 150.

ACAL has a Programme of Regional Cooperation that has received support from FSB-ACAL, UNESCO, ICSU-COSTED and TWAS. The Programme has among its activities the maintenance of S&T databases on research institutions, scientific events, graduate education programmes and fellowships, and the dissemination of this information through its printed and electronic quarterly publication *Ciencia en América Latina*. It also includes support to scientific activities, mainly to encourage the participation of scientists in training courses and research activities for short periods; the promotion of regional and sub-regional networks; and more recently, the organization of the ACAL forum on science policy. Scientists from Argentina, Bolivia, Brazil, Colombia, Costa Rica, Chile, Cuba, Ecuador, Guatemala, Mexico, Panama, Paraguay, Peru, Uruguay and Venezuela have participated in the Programme of Regional Cooperation. ACAL also has the Centre for Science Studies, a research unit at its headquarters devoted to the monitoring and evaluation of S&T in Latin America.

employment. In fact, if we compare the data published by the Interamerican Development Bank (1993) for the decades 1970-80 and 1980-90, it is clear that for all the countries of the region combined, the average annual growth rate of GDP per capita declined from 3.3% to –1.1%, at the same time as the average annual growth rate of GDI dropped from 7.2% to –3.0%. In addition, some countries had a three-figure annual inflation rate throughout the 1980s.

The countries of Latin America were thus confronted with extremely complex situations characterized by external pressures and domestic strife arising from the unsatisfied demands of large sectors of the population in the areas of education, health, housing and public services. The search for financial resources and the formulation of responses to the pressing demands of the impoverished population filled the entire agenda of the governments. They had to dedicate most of their energies to managing the crisis from one day to the next, thus neglecting the implementation of the medium- and long-term policies that could provide the only guarantee for the attainment of sustainable and equitable development.

The over-extended application of the import substitution strategy (ISS) up to the late 1970s had detrimental effects on the global competitiveness of the Latin American economies. The application of the ISS allowed the economies of the region to report high growth rates and make headway through the so-called easier stages of import substitution-driven industrialization. However, the lack of S&T capacity needed to move into the next stage of local production of manufactured goods and equipment quickly became evident. The net result was that as Latin America entered the 1980s, all the countries of the region, even those more advanced in the implementation of the ISS, suffered stagnation of economic growth, at the same time as losing market share in world trade and increasing their dependence on imported technologies.

The privileges afforded by protected domestic markets tended to encourage the development of a passive government-provides-all mindset among businessmen, and to discourage the spirit of competitiveness and innovation characteristic of a modern enterprise. These facts could explain, at least partially, the profound impact caused by the liberalization and opening of trade policies on most enterprises in Latin America.

The recent adjustment and stabilization programmes, conceived as solutions to the crisis, have failed to provide the long-awaited economic growth with equity. Rather, the opposite has come about. The Mexican crisis of the first months of 1995, and the effect it had on the rest of the regional economies, underlined the fragility of the solutions to the crisis implemented by the countries concerned. The crisis has also made evident both the strategic nature of the education and S&T sectors in their contributions to development, and the need to bring them up to date in order for them to be able to contribute to satisfying the demands for modernizing the Latin American economies.

The recent evolution of the world economy, marked by economic, financial and technological globalization, poses a great challenge to Latin American countries as they continue their efforts to change their traditional role in world trade, which in large part is still based on the export of commodities and low-value goods. The Latin American countries must replace their current role by a more competitive one based on exports of goods with high added value, and this requires that the education and S&T sectors play leading roles. Unfortunately, as has already been underlined, the deteriorating economic situation of the 1980s resulted in reduced expenditure on education and on S&T virtually throughout the region.

In the light of the transformations taking place in the world, it is necessary for the governments of the region to carry out an evaluation of the education, S&T and industrial sectors with a view to identifying strengths and weaknesses. This evaluation would also serve as a basis for implementing reforms to guarantee effective cooperation by each sector in the attainment of development goals. As indicated by Papon and Barré (1993), the main role of national governments with respect to the S&T system is that of a 'regulator'. The government carries out the strategic analysis and predictions at the national level as well as the evaluation of the work and operation of public research organizations, universities and research agencies, and also the follow-up of the interfacing between the S&T national system and the industrial and educational sectors, other sectors of state intervention and society in general.

S&T, industrialization and economic growth

Industrialized and developing countries differ both in their capacity to create new knowledge and in their ability to apply it. In most Latin American countries, the limited capacity of the S&T sector to generate and apply new knowledge to the industrial sector is reflected in the obsolescence of the industrial infrastructure. It also explains the low competitiveness of enterprises, the economies' progressive loss of market share in international trade and their growing dependence upon industrialized countries.

Rapid advances made in production technologies and new conditions of competition prevailing in international trade have caused a rapid erosion of the comparative advantages of Latin American countries, advantages based on an abundance of natural resources and low labour costs. The challenge is to achieve specialization of production, built on the creation and reinforcement of new comparative advantages arising from the generation and application through R&D of new S&T accomplishments. Latin American countries need to foster R&D specialization in order to reach the rate of innovation required to maintain the levels of competitiveness demanded by the international markets.

Although a certain level of consolidation of the S&T sector is apparent in several countries in the region (Table 1), it is also true that most research activities bear no relation to the productive sector. Moreover, it is well known that very few enterprises have their own R&D divisions geared to respond to technological modernization demands. Nevertheless, as certain successful results confirm, it is fair to say that in recent years serious efforts have been made to foster cooperation between S&T and industry, both at a regional and a national level.

The lack of in-house R&D in most of the enterprises of the region tends to limit the diffusion of technologies and also an enterprise's ability to absorb them. The establishment of an R&D facility gives a company the opportunity to formulate its needs in research terms. R&D is a prerequisite to reaching the levels of competitiveness required to participate in the most dynamic international tradeflows, which are characterized by intensive technology. In this regard, Chesnais (1990) states that innovation is the result of a very lengthy and complex process of accumulation and appropriation of technology, and that the capacity of an enterprise to assimilate scientific knowledge depends on whether it has ever participated in the production of knowledge in similar areas.

In the light of the difficulty in setting up in-house R&D facilities, due to lack of incentives, shortage of trained personnel and the high investment involved, companies would be advised to establish mechanisms for industry-research cooperation which, at least for the time being, could satisfy the demands for R&D in the process of innovation. To this end, it might be necessary for the industrial sector to approach the research centres and for the S&T sector to set up the structures required to allow it to monitor the problems and demands of industry.

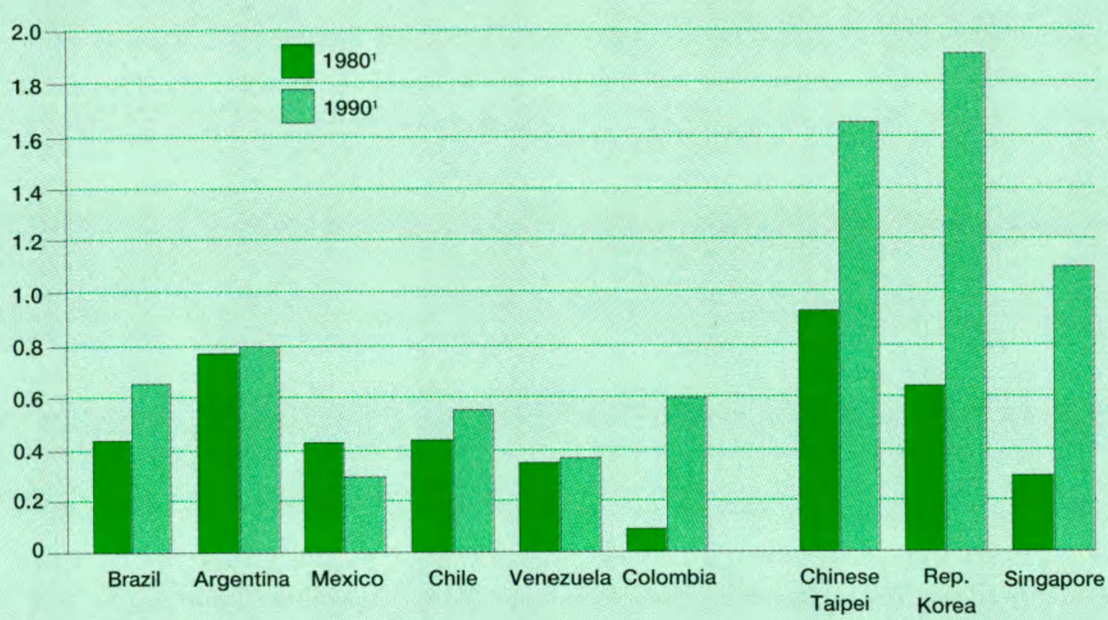
Precisely with the intention of building knowledge-intensive economies, as suggested by the OECD (1992), the national organizations responsible for S&T, as well as national R&D capacity, industrial R&D capacity, educational and training institutions and engineering design capacity, should all contribute to the establishment of national innovation systems to foster cooperation among the various actors involved in the innovation process. These systems should also encourage the formation of strategic alliances with multinational enterprises willing to contribute technological and financial resources, as well as to provide access to international markets. In this way, the minimal R&D endogenous capacity required for the transfer and adaptation of technologies will be created, facilitating access to global networks of technical cooperation and modern management and production organization systems.

As Quenan *et al.* (1994) indicate, the economic prospects of Latin America will depend on the potential competitiveness of the economies most exposed to the international marketplace. To this end, continual adjustments in the quality of specialization are required in order to maintain the competitive advantages that derive mostly from technological innovation.

The successful harmonization of S&T and industrialization policies

During the 1980s, the Republic of Korea, Singapore and Chinese Taipei, three of what have been termed the newly industrialized countries (NICs) of Asia, took steps to increase their expenditure on R&D (Figure 3). The situation was altogether different during that same period in Argentina, Brazil, Chile, Colombia, Mexico

FIGURE 3
R&D EXPENDITURE (GERD) AS % OF GDP IN SELECTED COUNTRIES OF LATIN AMERICA AND THE NICS, 1980 AND 1990



1. Or nearest available year.

Sources: ACAL, 1994; UNESCO, 1993.

and Venezuela, the countries in Latin America with the highest scientific production (see also Table 3). Similarly, it is also apparent that as a result of their human resource training policy for R&D, the NICs had acheived, by 1990, a number of researchers per million inhabitants several times higher than the six Latin American countries considered (Figure 4). These differences in the indicators for expenditure and human resources dedicated to R&D by the two groups of countries have their roots in the different roles assigned by these countries to S&T in their development processes.

Regarding scientific production, measured by the number of publications in journals with international circulation, we find similar levels in both groups of countries (Table 3). However, when these figures are expressed in terms of the total population, it is apparent that the values for Singapore and Chinese Taipei are several times higher than the others (Figure 5).

If we refer to the scientific and economic development indicators set out in Table 3, the temptation is to imagine that an increase of expenditure on R&D and a larger population of scientists would be tantamount to higher economic growth. However, it should be noted that although the R&D infrastructure facilities constituted a fundamental pillar in elevating the productivity of the NICs, other determinant factors of success were involved. Among these factors were the progressive growth of higher-value-added manufactured exports; the adoption of economic stabilization programmes, including trade opening and monetary devaluation, which laid the

TABLE 3

R&D EXPENDITURE AND PERSONNEL, SCIENTIFIC PUBLICATIONS AND MACROECONOMIC VARIABLES IN LATIN AMERICA AND SELECTED NEWLY INDUSTRIALIZED COUNTRIES

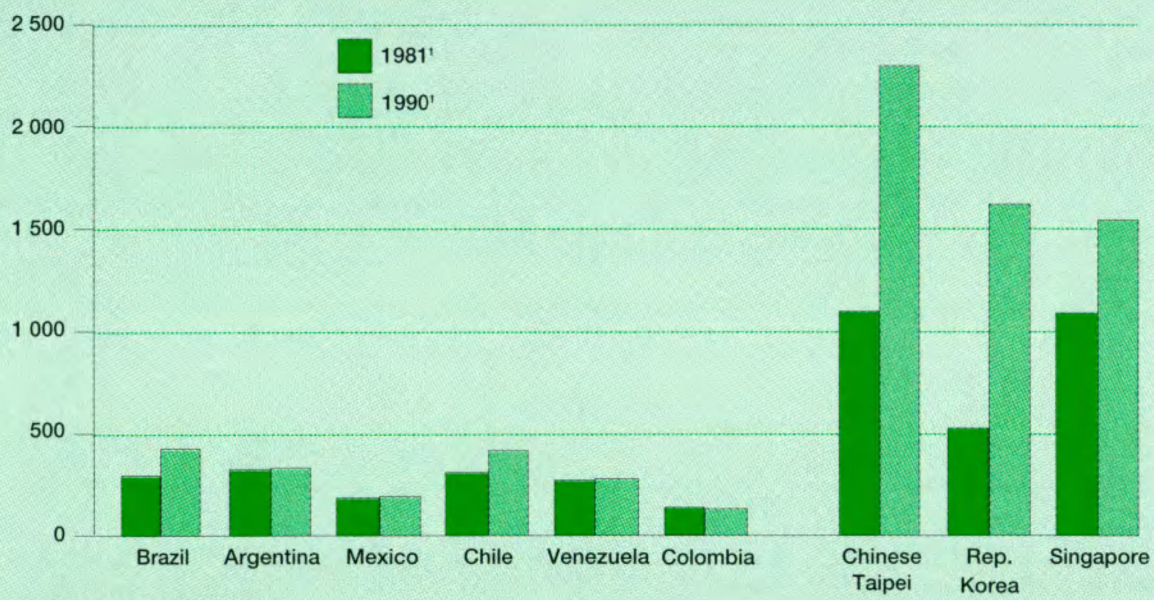
	R&D expenditure as % of GDP		R&D personnel per million inhabitants		Scientific publications			GNP average annual growth rate (%)		GNP per capita (US$)		
	1981[1]	1990[1]	1981[1]	1990[1]	1988	1990	1993	1965-80	1980-91	1970[1]	1980[1]	1990
Argentina	0.77	0.80 (92)	337	352 (88)	2 000	1 952	2 193	3.4	-0.4	1 020	1 970	2 400
Brazil	0.44 (80)	0.66	298 (83)	432	2 590	2 973	4 043	9.0	2.5	450	2 060	2 680
Colombia	0.10 (82)	0.60	139	138	–	188	194	5.7	3.7	340	1 190	1 260
Chile	0.44 (80)	0.55	320	422	1 500	1 098	1 231	1.9	3.6	840	2 100	1 940
Mexico	0.43 (80)	0.30	194 (84)	260 (91)	1 250	1 350	2 062	6.5	1.2	820	2 320	2 490
Venezuela	0.35 (84)	0.37	279 (83)	284 (89)	510	424	667	3.7	1.5	1 260	4 070	2 560
Rep. Korea	0.64	1.91	535	1 628	1 227	1 780	2 839	9.9	9.6	270	1 620	5 400
Singapore	0.30	1.10	1 096	1 546	653	843	1 033	10.0	6.6	950	4 550	11 160
Chinese Taipei	0.93	1.65	1 101	2 303	2 001	2 861	4 318	–	–	446 (65)	3 594 (85)	4 355

1. If different, the year of the data is given in parenthesis.

Sources: ACAL, 1994; ISI, 1988, 1990 and 1993; MCT, CNPq and IBICT, 1994; UNESCO, 1993 and 1994; World Bank, 1992*b* and 1993.

FIGURE 4

R&D PERSONNEL PER MILLION INHABITANTS IN SELECTED COUNTRIES OF LATIN AMERICA AND THE NICS, 1981 AND 1990



1. Or nearest available year.

Sources: ACAL, 1994; UNESCO, 1993.

grounds for competitiveness; the development of domestic demand (Lipietz, 1985; Bustelo, 1992); the adoption of a production-trade pattern making intensive use of human capital and technology based on a model of intra-industrial exchanges (Won Choi, 1993); and the redeployment to other countries of the segments of their industrial base corresponding to products with declining competitive advantages, at the same time as they set out to develop new industries for the export of products with higher value-added and higher technological input. This latter strategy of spatial globalization and regionalization was accomplished on the basis of direct foreign investments by multinational enterprises.

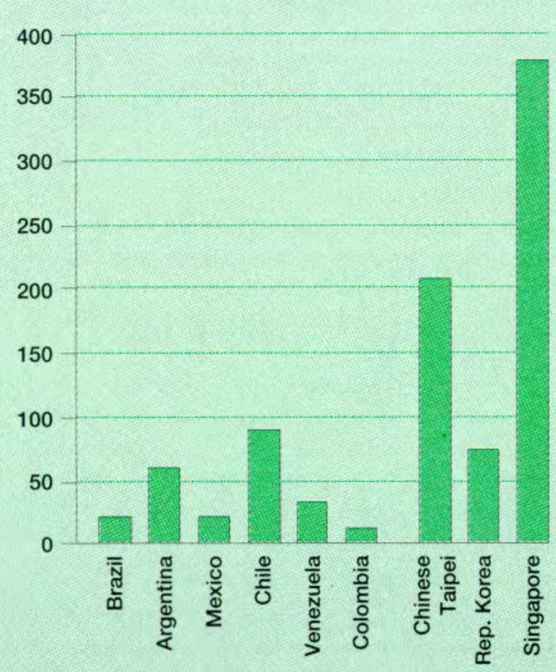
The success of the S&T-driven development strategy adopted by the NICs clearly demonstrated by the high rate of growth of their GDPs during the periods 1965-80 and 1980-91, as well as the extraordinary rise of their per capita income between 1982 and 1990 (Table 3), contrasts with the apparent low impact of S&T on the economies of Latin American countries during the same period. The low impact may be due to the meagre in-house R&D capacity within enterprises and the paucity of cooperation between the S&T and the industrial sectors (as noted above). In fact, unlike the majority of Latin American countries, the NICs conceived their S&T policy in terms of the identification of market needs and of a close linkage of R&D staff with the process of innovation. One of the main objectives of the NIC governments has been the creation of an endogenous S&T capacity geared to the strengthening of industrial production, so that it responds to the demands of the international markets (Okamura and Henry, 1993).

Another factor for success in the implementation of the S&T-driven development strategy adopted by the

NICs is the role played by the state in the supply of the financial resources required to maintain research programmes with an emphasis on high technologies and basic sciences, and its contribution to the definition of priority research areas, as well as the establishment of institutional networks of S&T cooperation aimed at strengthening the process of innovation.

The case of the Republic of Korea illustrates the crucial role played by the state when it adopts an economic model geared to the exports of manufactured goods. In this regard, Orozco (1992) recalls that 'from the establishment of the Ministries of Science and Technology during the decade of the seventies, the policies in this area have been geared to the promotion of production and of the country as a whole', and that 'the Ministry of Education also understands very clearly that the path of technology transference leads to the generation of endogenous technology and is based on the training of scientists, engineers and technical staff.'

FIGURE 5
SCIENTIFIC PUBLICATIONS PER MILLION INHABITANTS IN SELECTED COUNTRIES OF LATIN AMERICA AND THE NICS, 1993



Sources: SCI, 1993; UNESCO, 1994.

The NIC governments have also made a strong contribution to the creation of in-house R&D divisions by implementing subsidy-based incentive policies, tax exemptions, promotion of strategic alliances with multinational companies in areas of high technology and support of human resource training efforts for R&D. There was also increasing investment in R&D by private enterprises – in strong contrast to the meagre contributions made by the private sector of Latin America to R&D work (Cardoza and Azuaje, 1992). The achievements in productivity and competitiveness of the enterprises in the NICs can be explained by the rapid inclusion of technical advances into their industrial processes and products.

Another conclusion we can draw from the successful experiences of the NICs is that the adoption of an S&T-driven industrial development model can only be achieved if the country already has a group of skilled managers: managers who understand the importance of providing industries with an endogenous R&D capacity and are committed to the implementation of the model. In addition, the process implemented by the NICs also teaches us that in order to design and set the industrial development strategies for the countries of the region, the .concerted participation of the various sectors involved in the innovation process is required. Only a synergic structure of this sort allowed the NICs to overcome the internal and external obstacles of backwardness and to succeed in modifying their patterns of international trade.

As Amable and Boyer (1991) point out, policies that foster the creation of virtuous circles are required, based on imitation, learning, innovation and competitiveness, and these in turn require a stable economic context to supply skilled labour, market information and adequate sources of financing, in particular for small and medium-sized companies. Technology policy should be understood as a means of impacting on the long-term determinants of economic growth. This calls for consistency between this policy and all spheres of economic and social life.

In summary, one could state that, in good measure, the success of the Asian economies is based on the support provided by S&T to the goals of diversification, industrial modernization and the conquest of markets for their high-technology input manufactures. As pointed out at the start of this chapter, similar consideration could also be given to other sectors having a significant S&T component, such as health, agriculture, environment and energy. It should also be emphasized that the contribution of S&T was possible thanks to the widespread belief by society in general of the importance of S&T for development, as well as the implementation of a pragmatic approach by governments as they integrated S&T policies and national development policies.

CONCLUDING REMARKS

The status of science in Latin America, and the issues raised throughout this chapter, lead us to propose the adoption for our region of a new S&T-based development model: one able to foster expanded coverage of the social rights of the population, help overcome economic stagnation and improve the position in international trade of Latin American countries. The formulation and implementation of development strategies by these countries call for the concerted participation of governments, the S&T sector, the production sector and other social sectors. This task should be granted the highest priority in the development plans of Latin American countries in the years to come, as we rapidly approach the next millennium.

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Western Europe

ROS HERMAN

A curious blending of secular and religious cultural traditions created in Europe a fertile, if not always approving, environment for new ideas, their development and implementation. This untamed garden has been evolving and cross-fertilizing with other traditions for 400 years, providing a rich topsoil for the recent rapid expansion in numbers and scope of its community of research and development (R&D) personnel, which now number 1 in 250 of its workforce and account for 2% of gross domestic product (GDP). This chapter will concern itself with frameworks for science in the member countries of the European Union (EU) and the European Free Trade Association (EFTA).

The averages mask a large variation between the different countries: Switzerland devoted 2.9% of its GDP to research and development in 1989, largely spent by industry, while for Greece the corresponding figure was 0.5%, mostly from public sources. For the majority of countries the percentage increased during the early 1980s, to fall off as recession hit in the late 1980s, and has still not fully recovered in the early 1990s. Overall a convergence can be observed between R&D-intensive countries – France, Germany, the Netherlands, Sweden, Switzerland and the UK – and the less R&D-intensive countries – Greece, Ireland, Portugal and Spain (Figure 1). Gross domestic expenditure on R&D (GERD) as a percentage of GDP is a useful indicator of how serious a country is about keeping up with new developments.

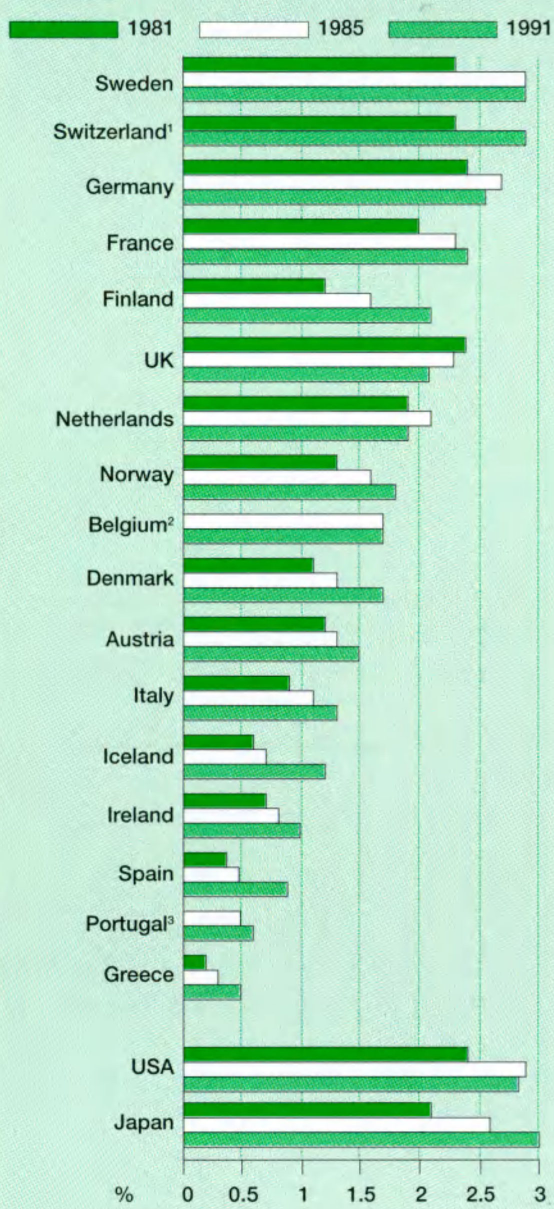
While Europe no longer dominates the world of science, the role of scientific research as a key to improving the quality of its citizens' lives underlies the strong support that European governments continue to provide for education and training, research and development and, increasingly, for dissemination and innovation. On average, industry provides about the same amount, though the part played by industry varies widely from country to country. Increasingly, such efforts are of international concern also: many scientists collaborate transnationally and some rely for their work on research facilities managed under multilateral collaboration. Many companies conduct R&D in more than one European country; and the EU plays an important role in encouraging and funding collaborative research within and beyond its 15 member states.

In this brief description of science in Western Europe it is not possible to illuminate more than a small corner of the activities entailed. I will, however, try to provide some introductory insight into how the different parts of what are now fairly complex communities of science fit together to fulfil the tasks set for them. With a variety of histories and cultures as backdrops, even in this small geographical region there are examples of many different ways of organizing science. I shall begin by looking at some of the typical approaches and then turn to more general characteristics of scientific output, higher education, economic impact and a new type of approach to science policy that is beginning to pervade the region. The conclusion will consider the unifying forces at work in science in Europe, without forgetting that diversity and autonomy have always characterized dynamic and innovative science.

NATIONAL RESEARCH SYSTEMS

Government frameworks for science are for the most part recent impositions on systems for research that have grown up through the efforts of individuals and private enterprises. In Europe the smaller countries have been persuaded to follow their larger counterparts in formalizing and actively strengthening such arrangements: these structures are now a significant though not all-pervasive part of the system. They will therefore form the core of our initial discussions here, in which I will present a tentative categorization of three types of system exemplified in Europe and based around the oldest and best-established traditions (Table 1):

FIGURE 1
GROSS DOMESTIC EXPENDITURE ON R&D (GERD) AS A PERCENTAGE OF GROSS DOMESTIC PRODUCT (GDP)



1. Bottom bar – 1989 figures.
2. Bottom bar – 1990 figures.
3. Figures are 1988 and 1990, respectively.

Source: OECD, 1994*b*.

A. Countries in the first category spend highly on R&D, with industry playing a dominant role. They are governed federally, with levels of government sharing responsibility for R&D. Federal governments guide overall strategy, while regions work closely with local industry and universities without encroaching on autonomy. Germany, Switzerland and Belgium come into this category.

B. Countries in the second category hold back from setting detailed policies. Nevertheless the state plays a significant role in funding, especially through research in universities.

Agencies such as research councils and innovation agencies mediate centrally set agendas, leaving a measure of autonomy to academic researchers. Examples include the UK and smaller northern European countries.

C. Countries in the third category tend to work out of more centralized, unified systems of government that traditionally plan and organize education, research and large sections of productive activity. The state provides as much as, and in some cases far more, support for R&D than industry. France is the largest of this group, with Italy and Spain less extreme examples, and Greece and Portugal with a much lower level of investment.

Size of country and degree of R&D intensity also affect the ways the systems work. In smaller countries the links between government and universities, institutes and industry are in general simpler, and policies are necessarily more selective, aiming to keep work in line with the country's industrial and intellectual strengths and financial means. Again, the less R&D-intensive countries are generally more academically oriented, relying largely on government support. However, investments are expected to yield fruit in terms of economic growth. The EU has been particularly concerned to build up the technology base of the poorer countries through a judicious mix of support for infrastructure and for scientific and technological expertise.

TABLE 1
CHARACTERISTICS OF RESEARCH SYSTEMS IN THREE COUNTRY GROUPINGS, 1991

Share of total expenditure on R&D by OECD countries (%)	Gross expenditure on R&D (GERD)/GDP				Proportion of gross expenditure on R&D		
	>2%	1.5-2.0%	1.0-1.5%	<1%	Spending by industry on R&D (%)	R&D carried out in industry (%)	Government spending on defence R&D (%)
Category A							
10.1	Germany				61.4	69.0	3.9
1.2	Switzerland				74.5[1]	74.8[1]	5.3
0.8		Belgium			64.8	66.5	0.6
Category B							
5.4	UK				49.3	63.9	16.0
1.4		Netherlands			51.2	53.2	1.6
1.2	Sweden				60.5	68.2	9.6
0.6			Austria		50.3	58.6[1]	0.0
0.5	Finland				56.3	57.0	0.5
0.4		Denmark			51.4	58.5	0.2
0.4		Norway			44.5	54.6	2.8
0.1			Ireland		59.4	62.0	0.0
Category C							
7.1	France				42.5	61.5	17.6
3.7			Italy		47.8	58.5	3.7
1.2				Spain	48.1	56.0	7.7
0.2				Portugal	27.0[2]	26.1[2]	4.9
0.1				Greece	21.7	26.1	0.8

1. 1989.
2. 1990.

Source: OECD, 1994*a*; OECD, 1994*b*.

Category A. Systems with a number of complementary sources of agenda setting and funding for R&D

The prototype for this small group is Germany, a country that in its reunified form will almost inevitably come to dominate Europe in science as in other spheres. Germany has set examples for Europe and the world in its development of the principle of research and autonomy in its education system, and in the application of science in modern industries, though it has fewer science graduates in its youthful workforce.

The research system in Germany is highly diverse, centrally conceived and coordinated, but for the most part run on the principle of institutional autonomy. That said, both central and regional governments share in the funding of research institutes and universities. A key part of the system is a group of national fora for debate on all kinds of policy affecting the research system. Politicians, scientists and industrialists meet regularly in the Science Council and at the federal/state commission level to act on educational and research planning and to develop policies, which can then be considered by all the parties, such as central and regional government, that will eventually have to participate in and fund initiatives. The basic principle is to allocate research tasks by 'subsidiarity'. Work should ideally be carried out in industry; if this is not possible – as in basic research, for example – universities are the proper places. A specialized institute should be set up only if it is absolutely necessary for reasons of efficiency and logistics, for example, if specialized equipment is needed. There are no fewer than four networks of research institutes: the *Max-Planck-Gesellschaft* (MPG – the Max-Planck Society – for basic research); the *Fraunhofer-Gesellschaft* (Fraunhofer Society – for applied research); the Association of National Research Centres (institutes based around large and/or expensive experimental facilities); and the 'blue list' laboratories which perform basic research associated with public missions such as health and social welfare. In addition there is a generous allocation to the national research council, the *Deutsche Forschungsgemeinschaft* (DFG – German Research Society). Germany has recently formed a 'superministry' for education, science, research and technology, which has been nicknamed the 'Ministry for the Future'. Backed up by such laboratories and by direct state support, companies invest heavily and systematically in research.

Universities are seen as a stronghold of basic research, although it is acknowledged that not all students are to be trained as researchers and that concentration of resources through differentiation and specialization is necessary if university research is to stay internationally competitive and not lose expertise to the well-funded and equipped laboratories. The regional governments are responsible for planning and running their local universities, and it is also up to the regions to see that their local institutions play their part in supporting the innovation process, which is seen as a series of concurrent interactive processes with heavy dependence on basic science and scientific engineering at every step.

The strength of the German model has been demonstrated in the way that Germany has systematically integrated the science system of the former German Democratic Republic. The Science Council reviewed the strengths and weaknesses of its resources for science and the plans for the future offered by the various institutes. The resulting plan recommended that some institutes be incorporated into the national networks and others adapted to make this possible. Non-viable institutions, including the Academy of Sciences of the GDR, have been replaced by a number of regionally-based institutions.

Politically, Switzerland is highly decentralized, so that the federal government plays only a limited part in intervening in science and technology policy. On the whole, industry, through its large share of science expenditure, dominates R&D activity, perhaps even more than in any other country in Europe, and indeed Switzerland files more patent applications per capita than any other country. Nevertheless, government concerns that industry is not keeping up with the very latest technologies have prompted some activities at a national level to promote R&D in specific areas, as well as initiatives in advanced vocational and research training.

While the universities are mainly supported by the cantons, two Federal Technical Institutes and several research institutions are directly financed and largely controlled by the federal government. The *Fonds national pour la recherche scientifique* (Swiss National Science Foundation), as the major funding agency, receives nearly all its money from the federal government, which also stipulates some general guidelines for the use of these funds.

Over the last decade, Belgium has joined the list of Europe's officially federal states, and responsibility for R&D is now shared by the federal government, the communities and the regions.

More than twice as much is spent on R&D in industry as in the state sector in countries of this group.

Category B. Predominantly national systems with limited central control

The UK is the largest of such systems. Government funds for science come from central government through a large variety of ministries and agencies. Support for the 'science base' is provided via a range of loosely coordinated but increasingly mission-oriented research councils and through block funding for universities, as well as from private foundations and the EU. Most basic research is done in the universities, which are fairly free to plan their own work without outside interference. On the other hand financial constraints on such support make such institutions increasingly dependent on money for research associated with specific short- and medium-term objectives.

The system embodies a clear split between mission-oriented research, which is the responsibility of individual government departments, and knowledge-oriented research, which has for the most part been the job of the universities. Spending on mission-oriented research is dominated by that of the Ministry of Defence, which maintains its own network of laboratories as well as supporting substantial amounts of R&D in the industries that supply weapons and other high-tech equipment to defence forces. Such spending has decreased in recent years, as defence is no longer seen to be such a high national priority.

Ministries responsible for industry have in the past made substantial outlays in support of research in civil industry, both directly and as partners with industry in the so-called research associations that were designed to provide underpinning research for a variety of different industries. Government has been backing away for the last 15 years from such spending, regarding 'near-market' research as not appropriate for public support. Hence direct support of research in industry has declined. Moreover, the laboratories supporting manufacturing industry and agriculture were pruned throughout the 1980s, and in the 1990s many of them have been or are on the point of being privatized. Much research in the defence sector – which underpins a substantial export industry, for example in aerospace – is going the same way. Increasingly, then, agendas for such research, insofar as it continues, are market-led rather than centrally defined.

While there is no single ministry for research in the UK, the recently created Office of Science and Technology, part of the Office of Public Service and Science, creates a focus for government efforts to influence science as a whole.

The small but technologically ambitious countries of the north, particularly the Scandinavian countries, which also have their own research grouping, operate this way. Such countries rely on industry and high technology for a large part of their gross domestic product and have long scientific and innovative traditions. A common theme of their current policies is to adapt and strengthen their knowledge base through developing their university systems, for example by developing university colleges with a strong emphasis on research. At the same time governments are identifying strengths and weaknesses in the areas related to their respective industrial strengths with a view to directing funds to ensure effective development across the spectrum from basic to applied research and innovation. Finland, and particularly Sweden, are the highest proportionate spenders on R&D: the Netherlands' contribution has declined in recent years, with funding in Denmark and Norway rising. Austria's contribution is also climbing but remains behind. Ireland is still way down at the bottom of this group. Not surprisingly, the two latter countries share a brain-drain problem: well-educated citizens see no opportunities at home and are attracted to countries where there is greater demand for their skills.

In all these countries, industry performs between one and two times the amount of R&D carried out in the state sector.

Category C. More centralized, state-driven R&D systems

In the Mediterranean countries academic activity and attainment are well respected for their own sakes and as a contribution to national culture, personal aspirations and self-fulfilment. Research activity, particularly in science and engineering, is shared between dedicated institutes, often centrally planned, organized and funded, and the university system. It comes under the ministry for higher education and research. The strong role of government in driving and controlling national infrastructures and economies has also led to much applied research being carried out at the expense of and under the control of the state in nationalized industries.

The focus of the country's research effort is a single government-funded organization which acts as an umbrella for a large network of research laboratories. Researchers are then for the most part employees of the organization. The most extreme form of this pattern is France, the leader and role model for this group of countries, with its *Centre national de la recherche scientifique* (CNRS – National Centre for Scientific Research). The CNRS covers every subject from astrophysics to the humanities and is the major voice for science in the country. This makes it a very strong national focus for science. There are a number of free-standing research laboratories, but most research centres are based at universities, though few CNRS staff undertake teaching. Universities may bid to have a centre based at their campus.

The region around Paris has in the past hosted a disproportionate number of CNRS laboratories, but the balance is now changing in favour of other regions. Regional authorities are important sources for funds in support of specific policies for their area, and these may include the agenda of attracting CNRS laboratories, possibly to help stimulate investment by industry. CNRS administration has been decentralized to help such relationships develop. Each of the seven subject groups also has its regional policy, spreading its work out to develop centres of excellence in each region. There are also a number of agencies that carry out mission-oriented science in space, health and other areas.

Universities are in future to play a bigger role in research, and the government hopes to improve mobility between the universities and the research institutes, which will be looking for many new young recruits as a generation retires over the next decade. Both research institutes and universities are to look for opportunities to work with such outside bodies as industry and local, regional and national government. Industry has recently been drawn into setting agendas for science on a national basis, and there is to be an annual national plan for science in which objectives and achievements are laid out for discussion.

Italy, too, has its network of research institutes of the *Consiglio Nazionale delle Ricerche* (CNR – National Council for Research), in which the state conducts research in designated subjects within basic science and health; the state's research network for energy (*Ente per le Nuove Tecnologie, l'Energia e l'Ambiente* – ENEA) has recently had its role – and its title – expanded to cover new technologies and environment as well, and there is also a relatively new space agency. Like France, Italy has a ministry that covers higher education and research: it defines priorities as well as supervising and supporting public and some industrial research. An applied research fund provides a wide range of options, including support of basic research in industry, national research programmes for strategic technologies, preliminary work for international collaborations and evaluation.

Taken together, the universities do almost as much research as the government institutes. They are also under state control and have joined the state networks for research under the jurisdiction of the Ministry for

Universities and Scientific and Technological Research. A three-year development plan has added new universities to the system to reduce over-crowding, and the state will also be strengthening research training and university autonomy.

Spain rapidly expanded spending on R&D during the 1980s. It has a national R&D plan that promotes training of research personnel, starts research programmes and supports the scientific and technical infrastructure. An interministerial commission for science and technology drafts and executes the plan: several other organizations promote the objectives of the plan and evaluate its execution. Once again, government laboratories and universities are almost equally balanced, with industry playing an increasing part on the national scene.

Greece and Portugal lack networks of research institutes, and R&D is concentrated in their university systems. They differ from the smaller countries in the north in that the state will have to play a central role in encouraging industrial development and expansion until the resulting industries are ready to take the initiative in undertaking and setting the agenda for research.

In France, Spain and Italy industry performs between one and two times the R&D carried out in the state sector, while in Greece and Portugal industry performs only one-third of that carried out by the state.

COMMON ISSUES AND CURRENT TRANSFORMATIONS

These systems have evolved largely since the Second World War: their similarities and differences arise from the interaction between the essentially national political culture and the worlds of science, created partly by national cultures of science but also heavily influenced by the nature of the international scientific enterprise. They represent the attempts of individual governments to take responsibility for promoting science through the provision of adequate finance, at the same time as moulding systems so that they deliver science in such a way as to meet the needs of the state.

Measures of output

It is important to remember that in Europe the newish systems are only a recent overlay on societies and networks of natural philosophers that have been evolving since the 17th century, often with little or haphazard support from private and public sources. It is in such contexts that the foundations of the scientific revolution were laid, and the achievements of the Industrial Revolution formulated and consolidated. Europe's domination of the world of science has, of course, diminished as other countries, notably the USA, have jumped ahead. But, for their populations and even their economic clout, the countries of Europe still make a disproportionate impact on the world's science.

Basic researchers aim high: their ambition is to achieve breakthroughs in science that overturn previous theories, demonstrate results not hitherto possible or achieve original solutions to problems others have found intractable. The most outstanding of such achievements are rewarded by such prizes as the three annual Nobel Prizes for science, and, since they go to top scientists anywhere in the world, they can be used as a measure of a country's scientific standing and achievement in basic science (Table 2). Scientists of German and British nationality received most prizes up until the early 1950s; the USA then took over the lead and has maintained it ever since. The UK and Germany now vie for second place, with France, Sweden and the Netherlands next, ahead of the former USSR and Japan. In terms of prizes awarded over recent years the USA is way ahead of any other country; in fact, there are few prizes awarded that are not shared by a scientist in the USA. While Germany was the star of Europe before the Second World War, the UK has dominated the European scene ever since, though to a decreasing extent.

TABLE 2
NOBEL PRIZES AWARDED IN NATURAL SCIENCES (PHYSICS, CHEMISTRY AND PHYSIOLOGY OR MEDICINE) BY NATIONALITY

Country	1901-31	1932-62	1963-93	Current population (millions)	Index of Nobel success (no. prizes 1963-93 per 10 million population)
Austria	3.00	2.50	0.33	7.62	0.43
Belgium	1.00	1.00	1.67	9.88	1.69
Denmark	4.00	0.50	0.33	5.13	0.64
Finland	0.00	1.00	0.00	4.96	0.00
France	11.00	1.00	5.16	56.16	0.91
Germany	26.00	8.00	8.16	78.27	1.04
Greece	0.00	0.00	0.00	9.98	0.00
Iceland	0.00	0.00	0.00	0.25	0.00
Ireland	0.00	0.00	0.00	3.52	0.00
Italy	1.00	2.00	1.75	57.48	0.30
Luxembourg	0.00	0.00	0.00	0.37	0.00
Netherlands	4.00	1.00	0.50	14.88	0.34
Norway	0.00	0.00	0.50	4.22	1.18
Portugal	0.00	0.50	0.00	10.47	0.00
Spain	0.50	0.00	0.00	38.81	0.00
Sweden	5.50	2.00	2.33	8.50	2.71
Switzerland	3.50	3.00	3.33	6.58	5.06
UK	12.50	15.83	11.50	57.21	2.01
USA	2.50	31.50	49.33	249.93	1.97
Japan	0.00	0.00	1.00	123.12	0.08

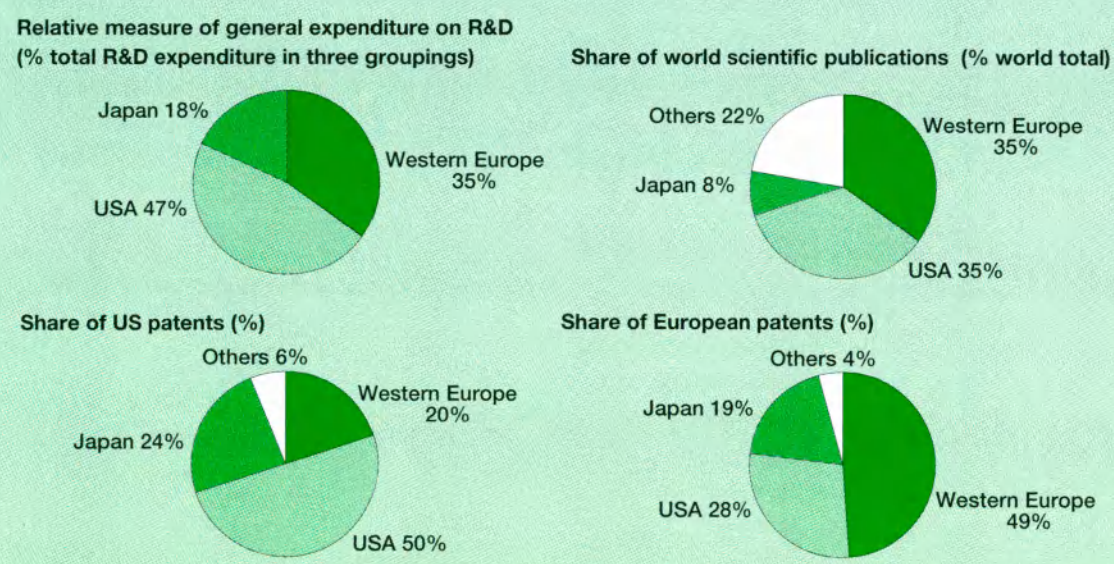
In more quantitative terms, the outputs from science can be assessed and compared using a number of yardsticks. In Figure 2 shares in world publication and patenting are compared with the level of gross national product and share of scientific investment. The results confirm the general image of Europe as a scientifically sophisticated part of the world, but with a better performance in science than in patenting activity. The differences, however, are not great, apart from Japan's relatively modest contribution to the scientific literature. Care must be exercised, however, in the interpretation of bibliometric data, which in large part show a bias towards English-language publications.

The figure shows that Western Europe and the USA are roughly evenly balanced in terms of scientific publications and gross domestic product. However, the USA spends rather more on R&D to achieve this: on the other hand it achieves more in terms of patents. Japan spends relatively a slightly greater percentage of gross domestic product on R&D; while its scientific publications lag, it achieves well in patents, being granted more patents in the USA than the whole of Europe.

The Western European governments, as reviewed by the policy makers of the Organisation for Economic Co-operation and Development (OECD), have encour-

FIGURE 2
OUTPUT OF SCIENTIFIC AND TECHNICAL ACTIVITY FOR COUNTRY GROUPINGS, 1993

Gross domestic product, 1992	Western Europe	4 108 billion ECU
	USA	4 240 billion ECU
	Japan	1 590 billion ECU



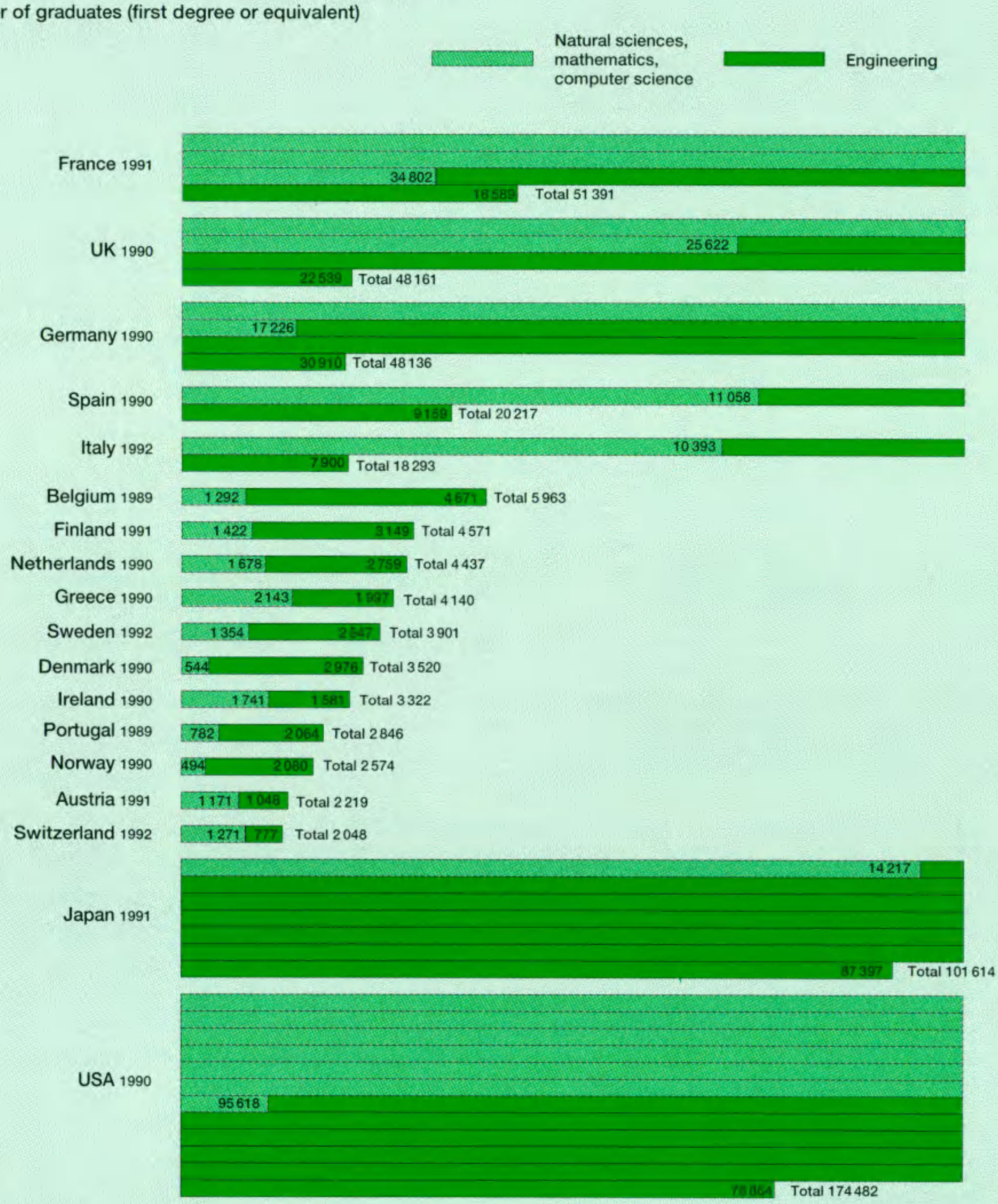
Source: European Commission, 1994.

aged the development of scientific research and higher education. They have, by and large, consolidated their systems in such a way as to maintain the principles of the natural philosophers: the idea of autonomy for researchers combined with allocation and reward systems based on peer review. This approach has been fairly successful in promoting research of good quality and also in providing a cadre of teachers ready to teach the increasing numbers of young people who enter higher education.

Higher education

European countries for the most part invest heavily in education as a whole. Education is seen as the key to the fulfilment of personal and national aspirations, including the generation of prosperity through maintaining and developing a skilled workforce and the development of knowledgeable, responsible and reflective citizens. However, the proportion of the young workforce (aged 25-34) with a university education, varying between 17% in Spain and 5% in Portugal in 1991, with the larger countries achieving between 11% and 15%, is much lower than in the USA with 24%. In terms of research scientists and engineers in the labour force the European Community averaged in 1991 4.3 per 1 000, with Germany (5.9) and France (5.2) slightly ahead of the UK. This compares with 7.6 per 1 000 for the USA and 9.2 per

FIGURE 3
GRADUATES IN NATURAL SCIENCES AND ENGINEERING
Number of graduates (first degree or equivalent)



Source: UNESCO, 1994.

1 000 for Japan. Thus Europe is well behind in terms of the general spread of scientific expertise in the labour force. This is particularly worrying in view of the discovery of a direct link between the level of education achieved and chance of obtaining employment: some are suggesting that one key to tackling Europe's high levels of unemployment is through providing more opportunities for its young people to train and study.

Even so, tertiary education in Europe has expanded rapidly since the Second World War; growth has, however, generated its own problems. Expansion has rarely been accompanied by commensurate growth in funding, particularly in recent years, and in many countries academics have come under pressure both as teachers and researchers. Higher education institutions are still expected to provide a reservoir of creativity, scholarship, autonomy, independence and objectivity that can form an important source of review and comment on the workings of society. To resolve the problems involved in reconciling the development of Europe's tradition of long-term

TABLE 3
SCIENTISTS AND ENGINEERS ENGAGED IN RESEARCH AND DEVELOPMENT

Country	Absolute numbers (1989)[1]	Absolute numbers (1993)[1]	Research scientists and engineers per 1 000 labour force (1991)[1]
Austria	8 782	–	2.5 (1989)
Belgium	17 583	18 465 (1990)	4.3
Denmark	10 962	12 970	4.1
Finland	10 593 (1987)	14 030 (1991)	5.5
France	120 430	138 434	5.2
Germany	176 401	181 794 (1990)	5.9 (1989)
Greece	5 299	6 230 (1991)	1.5
Iceland	685	720	4.8
Ireland	4 165	5 965	4.0
Italy	76 074	72 968	3.1
Netherlands	26 680	26 680	4.0 (1989)
Norway	12 156	14 424	6.3
Portugal	5 456	5 908 (1990)	1.2 (1990)
Spain	32 811	41 901	2.6
Sweden	25 585	27 445	5.9
Switzerland	14 250	–	5.2 (1992)
UK	134 000	123 000 (1992)	4.5
USA	949 300	887 600	7.6 (1989)
Japan	457 522	518 659	9.2

1. Or latest available year (given in parentheses).

Source: European Commission, 1994; OECD, 1994*a*, vol. 2.

academic achievement with short-term pressures is one of the major challenges of the decade. Recent policy has tended to combine focusing on participation rates with measures that will ensure that research of high quality and relevance takes place. A common response has been to increase the proportion of support for research in universities that is allocated by competitive means from external agencies, such as government and industry. In addition, some countries such as France, the Netherlands, Denmark, Finland and Switzerland are reforming their university systems as a whole, paying special attention to improving opportunities for research and research training at postgraduate levels.

Developing and applying research

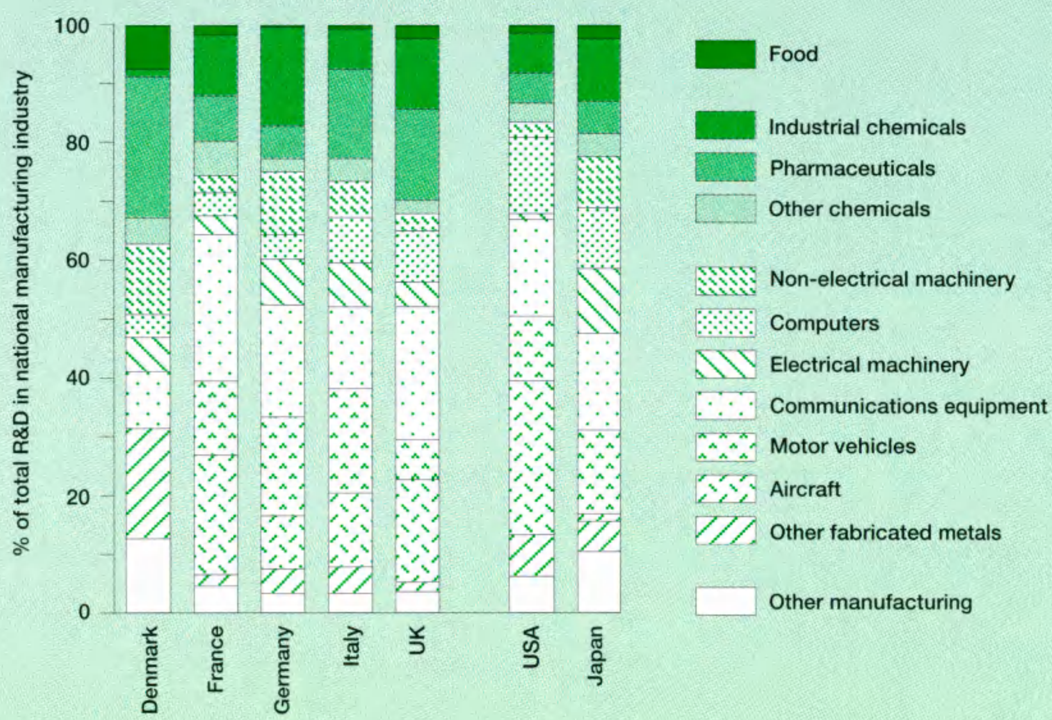
The availability of such personnel has enabled industry and public services to expand and increase their technical expertise and thus develop sophisticated products and techniques.

Innovation is essential to keep industry's products competitive. Some industries are more research intensive – i.e. have a higher ratio of investment in R&D to production – than others. In Europe the industries with the highest ratios are aerospace, pharmaceuticals, electronics, computers and chemicals, with motor vehicles, electrical machinery and instruments also significant. Compared with competitors in the USA and Japan, Europe produces most goods in three of these groupings: chemicals, pharmaceuticals and motor vehicles. Many of the companies involved are large and multinational: they produce and even carry out research in several countries. They can thus profit from research done almost anywhere, even outside Europe: technical advance in biotechnology for example has been more easily appropriated from research in the USA than from Europe. However, Europe produces less than the other two in the key areas of electronics and data processing and office equipment, and its position is deteriorating. Moreover there are some areas in which industry has conducted basic research: electronics and pharmaceuticals are two examples; the new science of genetic engineering can hardly be distinguished in terms such as basic and applied from its offspring biotechnology. Europe occupies a middle rank for the production of aerospace and scientific equipment.

For the most part research and development in industry – which accounts for well over half of R&D investment in most technologically advanced countries – builds on scientific results often generated in the public sector, and in some countries (Germany being the most notable exception) industry has traditionally worked independently of basic research institutions. Many governments have encouraged companies to develop technologically: through subsidizing research for products in which it was directly interested; in providing research institutes where expertise is available; in providing tax advantages and other financial incentives; in promoting schemes for industry to exchange ideas with scientists. In some countries government provides a significant proportion of the cost of such research: in France, Sweden, the UK and Germany 20-30% of government R&D funds go to industry, largely in the defence sector. In addition, most European governments spend between 20% and 30% of their civil appropriations on various schemes for economic development, with Austria and Belgium spending less and Ireland nearly half in this way.

A more recent development is to invite industry to participate in setting the agenda for research in the public domain, particularly where pressure on funds has made some selectivity between subjects inevitable. Almost all the European countries have conducted, or are in the course of conducting, reviews of where their technological future lies and how the state can underpin its development. Often this involves having expert panels match exciting areas of basic research with the technological opportunities that new developments could open up. The results help companies to plan their own work as well as guiding governments, which can arrange their funding plans

FIGURE 4
RESEARCH IN MANUFACTURING INDUSTRIES: DIFFERENT PATTERNS OF NATIONAL INVOLVEMENT, 1990



Note: Only the most significant groups and subgroups are shown.
Source: OECD, 1994a.

and infrastructures in such a way as positively to influence the R&D activities of large and small companies, particularly in terms of long-term work and work 'at the margins', i.e., what they might not undertake except with some public involvement.

We have seen that such efforts have cost a significant share of GDP – yet they have not altogether succeeded in keeping Europe's industries competitive. In particular Europe has a problem with productivity: output per fulltime equivalent employee is way below that for Japan and under half that of the USA. While Europe has a reasonable market share in high-tech exports, her internal markets are not coherent or strong enough to maintain adequate levels of employment for her workforce. Tackling such problems is a high priority for regional and national governments and for the EU as a whole, and governmental approaches to R&D, as we shall see below, do not tend to be designed accordingly.

And so in the last few decades, European governments have arrived at a new view of the role that science plays in the life of the state, and the philosophy of their involvement with it has altered accordingly. The most dramatic change has been that the earlier assumption that in order to achieve such objectives as economic competitiveness it was necessary only to provide sufficient financial support for education and research is no longer tenable. Governments need to examine all aspects of policy in which they are involved in order to tackle such problems, including involvement with science by the state and in the nation as a whole.

The new science policies

An important recent change is that the role of the state has tended to move from that of being a central actor in the technological innovation process to that of coordinating, facilitating and promoting it. In addition to considering only the early stages, that is, basic research, the state now considers technology transfer as being within its remit. It not only supports such efforts financially, but also comments on organizational, institutional and cultural aspects of technological practices. Rather than just being part of economic policy, R&D has become an independent policy field closely interlinked with other policy areas.

The new philosophy has resulted in changes in the structure of government organizations, as we have seen above; it has also resulted in specific measures and affected regional development policies.

Almost every country has new measures to strengthen its scientific infrastructure: for example, the Netherlands has developed a framework programme for science and technology in the 1990s, and has instituted a new network of scientific research colleges, and Portugal has put special emphasis on strengthening basic research through the PRAXIS programme of support for basic research and the CIENCIA programme to strengthen infrastructure in priority areas. In the area of the technology base, Spain has recently completed a technology action programme, and Italy has a fund for technology innovation and tax credits for firms. Dissemination of results is important too: the UK provides support for consultancy and improvement in management practice as well as a Senior Academics in Industry scheme.

A more integrated approach to science and its implementation has also concentrated the minds of planners on stimulating regional development by developing networks of contacts and particular specialisms. Such initiatives take place most naturally where local governments, for example in Germany and Switzerland, already play a significant part in funding R&D. However, such countries as the UK, Spain, France and Italy, where the regions have considerable powers but still make a relatively modest contribution to science and technology, have also embarked on regional policies designed to redress imbalances in wealth and employment, and also to build on existing local industrial and academic strengths. Even countries that have no regionalized policy structures have looked at such approaches: for example Greece has instituted technology parks in Athens, Patras, Salonica and Heraklion and plans to encourage the development of regional research and innovation magnets in Piraeus, Macedonia and Thrace.

While in many ways under attack from various elements in society, both intellectual and anti-intellectual, science remains for the most part a source of reliable and objective knowledge about the world. It is still generally accepted, for example, that the advancement of science is essential for improving health and the quality of life in general, and will continue to offer opportunities for economic growth and the satisfaction of human needs and aspirations. However, science and its applications are no longer accepted uncritically. A growing feature of the state's involvement with science concerns what the Germans call 'preventive research', work concerning the environmental and social effects of technological change, and the acceptability or understanding of science and its fruits by the public.

Thus all European states are looking carefully at the development of programmes relating to socio-economic objectives of major importance; promotion of the acceptance of science and technology by the public; assessment of ethical and social aspects of technological development; and the improvement of mechanisms and methods of assessing programmes.

Evolution and convergence of policy

Whether or not spending on R&D is centrally planned, it can be broken down into different subject areas. Such breakdowns allow observers to form an impression of the general priorities the country sets in terms of objectives for research and development. In recent years, for example, many European countries have increased their emphasis on the advancement of knowledge through basic research, while they have cut their spending on research into industrial productivity and production technologies and, even more dramatically, into energy. Spending on defence objectives, responsible for substantial proportions of R&D in the UK and France, has declined in priority, though it still accounts for 20% of the total governmental R&D funding for the EU. Space takes another substantial and increasing share. Research into health, environment and social structures and relationships has grown.

National science systems are changing in the light of these two sets of pressures, to stimulate growth and to harness science to global and social ends in a publicly acceptable way. So far the institutions that carry out research have not altered substantially from their post-war shape: such a change would take decades rather than years. Nevertheless, substantial modifications have taken place in the way science is handled within government, and also in the way industry runs its scientific research. Throughout, there is added emphasis on results, value for money and accountability. New layers of assessment and review are being added to peer review systems in order to feed in external criteria for the value that should be placed on research; these include analysis of the industrial and/or public implications of the results. Such efforts have had the effect of stimulating exciting innovations in teaching and research, but they have also stimulated a backlash, when the autonomy, scale and scope of knowledge-oriented work has come under threat.

WORKING TOGETHER

We have already noted a convergence in European approaches to research and development. This trend is also driven by cooperation manifested both through transnational collaboration and within the framework of multinational corporations. There is an increasing tendency for researchers from different countries to combine forces. This is true for all scientifically active countries, but those in European countries are more likely to publish with nationals of other countries than those in either the USA or Japan. Collaboration arises from bilateral and multilateral agreements of many kinds, often fostered by government or charitable grants for travel and equipment.

The tradition that scientists from different countries should meet and share their results and knowledge is as old as science itself, and has become increasingly institutionalized since the 19th century in such events as international meetings. A famous example is the series of Solvay conferences at which nuclear scientists met in the early 20th century. The idea of working together is more recent and has really only been made possible on a systematic basis by increasingly fast transport and the communication revolution. The increasing specialization of science has also put pressure on scientists to combine their work in this way, as indeed has the cost and scale of the equipment required for state-of-the-art work. The post-war years were a time of great optimism for science, combined with a driving force towards mutual understanding between nations: thus it became possible to embark on such ambitious multinational projects as the European Organization for Nuclear Research (CERN). Other organizations aspired to the setting up of ambitious centralized laboratories to pursue their work: examples include the European Molecular Biology Laboratory (EMBL), the European Southern Observatory (ESO) and the Joint Research Centre of the European Community. These mirrored only slightly less grandiose schemes undertaken nationally to enable scientists to keep ahead. Multilateral projects arose that were geared to more sanguine objectives than the promotion of basic research. These included the European Space Agency (ESA) and various aerospace and defence projects. It has been estimated that such joint expenditures account for some 3% of R&D spending in Europe.

Similar enterprises do, however, still come about when countries can agree on the need – a recent example in Europe is the European Synchrotron Radiation Facility (ESRF) at Grenoble in France. The scientific and technical case for this was made by the European Science Foundation (ESF), which since its establishment in 1974 has provided a forum where representatives of 56 funding agencies in the member states can meet, arrange collaboration and discuss matters relating to the changing shape of science and the best way to promote it. How to meet the new challenges set for European research is now a key part of the role of the ESF as a pan-European forum for national research funding organizations. The ESF has also advised the European Community on matters relating to basic science, and is represented on a new body set up by the European Commission, the European Science and Technology Assembly (ESTA). The realization of the importance of the European context for science is demonstrated by the recent birth of a number of other organizations, including the Academia Europea, the Alliance of European Academies (ALLEA) and the European Rectors Conference (CRE).

One of the concerns is about scientific facilities that are too expensive to provide for every group that wants to work on them: thus at supranational, national and even regional level equipment is shared by researchers from a number of different institutions. Even for slightly cheaper equipment, the outcome of competition for funds may determine whether or not a particular group will have access to the equipment that will or will not keep them up with the state of the art.

But in keeping with the more frugal approach to the funding of science nowadays, there is great reluctance to set up collaboration that involves massive capital investment and high running costs. It has also been shown that large laboratories set up with generous funding and given a virtually free hand often find it difficult to keep up with new trends and adapt to new ideas. A more usual approach is actively to promote 'virtual' collaboration, where work is done at the home bases of various groups of scientists who agree on a common objective and share out the operations necessary to complete the project. This is now the major strategy adopted for the collaboration that is encouraged by the EU.

The involvement of the EU in science and technology is in step with the tighter relationships between science and its applications documented above. The European Economic Community had no remit to promote science for its own sake: its research plans had to be geared to the economic advantage of the Community, just as the Joint Research Centre had to be geared to helping the member states use atomic energy. By the late 1970s it became clear that Europe's erstwhile preeminence in science was being eclipsed by the USA and Japan and, moreover, the members were also losing the battle for markets and technology: hence the need to give a European dimension to research, to standards and to the market base. Out of these imperatives arose the Framework programmes, designed to build collaboration in science with potential to improve economic competitiveness. Under Framework, the EU offers half the cost of projects in areas it has specified as being of particular interest. Researchers, who may work either in industry or in the public sector, must apply in groups involving at least two member states, and projects are assessed by peer review processes managed by the European Commission. The cost of these account for a further 4% of European outlays for R&D.

In the 1990s the Framework programmes have also been subject to the pressures on national systems mentioned above: to streamline even further the process of technological innovation, but also to look to such wider issues as environment and climate problems; regulation and the acceptability of technology; and the technical development of infrastructures for transport and information. The Treaty of Maastricht also brought within the EU's remit the objective of social cohesion between the member states and of coordination of national policies for research and technological development.

Studies of the impact of the Framework programmes on member states show that researchers profit from such collaboration by gaining access to complementary expertise and results, by the strengthening of European research and technological development links as well as by obtaining extra funding. Framework, it is felt, has contributed to creating a more stable collaborative environment or, to put it another way, to the formation of a genuine 'European scientific community'.

The idea that science is a common enterprise in which all nations can take part on equal terms has also fuelled the growth of such international organizations as the International Council of Scientific Unions (ICSU); harnessing science to more practical objectives on an international scale drove the evolution of the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO), for example. More recently the increasing complexity and expense of some scientific endeavours have fuelled the planning of certain projects on an intercontinental basis, for example, the Human Genome Project and the Joint Fusion Project. Europe plays its part in the discussion of such major projects, including through the Megascience Forum of the OECD.

CONCLUSION

Europe's 'untamed garden' of science is, as we have seen, a diverse and dynamic one. A number of forces are tending to bind its scientific communities in a network of common interests and agendas, and cooperative efforts are helping to bring the less mature scientific communities up to scratch. On the other hand, Europe's industries are under constant pressure to compete with each other and with non-European counterparts for key markets. Strong traditional dependencies on public involvement with industry and research may hold back competitiveness: states are now taking pains to diminish such dependencies and the protection of markets. Key objectives informing science policies are to create better employment prospects and to minimize state expenditures. Some countries in Europe do better than others in this regard, but it is clear that Europe as a whole needs to take care not to let the USA, Japan and South-East Asia in general win the race to apply new ideas and technologies.

Europe's scientists have gained attention – and often extra practical support – from the resulting interest in their work: on the other hand they are having to make sure that their research makes a useful and appropriate impact on the society or the business that sponsors it. The challenge now is for researchers to strike a balance between responding to short-term pressures and building on their strong tradition of achievement in basic science.

ACKNOWLEDGEMENTS

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This chapter was prepared and written in close collaboration with Professor Peter Fricker, Secretary General and Chief Executive of the European Science Foundation.

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Central Europe

ANTONI KUKLINSKI AND BOGDAN KACPRZYNSKI

The transformation of Central Europe[1] is a complicated and historical process with many dimensions. We may define transformation as a qualified structural change where the object of change will – after the consecutive stages of transformation – have a new identity. The question as to whether Central Europe will be able to create a new image and new identity during the first decade of the 21st century cannot be answered in a broad way since the countries of the region are in varying stages of the process of transformation: some of them are well advanced, some are just starting out on the difficult road of structural change; yet others are undecided and torn between the past of real socialism and the future of real capitalism. This is the definition of transformation in real terms, much more brutal than the elegant formulations related to the development of parliamentary democracy and a market economy in Central Europe.

The transformation of science

Transformation is a holistic process where successes and failures in one field have a deep impact on performance in the remaining ones. The transformation of science must therefore be seen in this holistic perspective. However, particular attention must be given to the relation between the transformation of science and the transformation of the economy, society and the state.

The transformation of science in Central Europe is the process of creating a new model of science. This implies the creation of:

- a new personality for the scientist;
- new patterns of motivation and behaviour on the part of the scientific community;
- a new institutional infrastructure;
- a new scope and structure to the demand for science (Kuklinski, 1994).

This new model of science needs to solve the dilemma of being national and European at the same time: national in the sense that the new model of science must be deeply incorporated into the tradition of national culture and into the systems of values and patterns of behaviour of the given society. The relationship of this model to the competitive challenges of the given national economy as related to the global economy is also important. In other words, this model of science must function within an efficient system for the creation and diffusion of innovation in the given country (OECD, 1992; Kacprzynski, 1994). This new model of science must also be European in the sense of being a creative adaptation to the conditions and parameters prevailing in the territory of the European Union.

THE BARRIERS ON THE ROAD TO THE FUTURE

We can perhaps begin by asking the question: how effective has the first stage of transformation been during the years 1989-95? In Central Europe the achievements have been very great. An optimistic interpretation is that the point of no return to the old order has already been reached. However, whatever the interpretation, we must acknowledge that the process of creating the new model has been much slower and less efficient than the importance of the historical opportunity might suggest. The barriers on the road to the future have proved, quite simply, to be far greater in number and impact than originally anticipated.

First was the legacy of real socialism in terms of both mental and material structures. With a certain degree of generalization we can say that the whole domain of science in Central Europe was, directly or indirectly, subordinated to the demand created by the military-industrial complex of the Soviet Empire. In

1. Central Europe is taken in this chapter as being a group of six countries – the Czech Republic, Slovakia, Poland, Hungary, Bulgaria and Romania – having strong common denominators: the experience of real socialism; the transformation process; and the prospect of joining the European Union in the future.

TABLE 1
BASIC INDICATORS FOR THE CENTRAL EUROPEAN COUNTRIES

	Year	Bulgaria	Czech Republic	Hungary	Poland	Romania	Slovakia
Area ('000 km^2)		110.9	78.9	93.0	312.7	237.5	49.0
Population ('000s)	1993	8 470	10 327	10 289	38 459	22 760	5 300
GDP (PPP[1])	1989	5 633	6 673	5 524	6 413	na	5 791
per capita US$	1992	na	6 827	5 399	4 137	3 854[2]	5 022
Growth in GDP (%)	1989-1993	–32.1	–17.9	–18.9	–14.2	–32.4	–21.6
Share of private	1989	8.9	3.1	14.5	14.7	2.5	3.1
enterprise in GDP (%)	1994	na	56	50	56	30	53
Inflow of foreign capital (US$, billions)	1990-1994	0.6[3]	3.7	8.5	4.3	1.2	1.5
Foreign debt (US$, billions)	1994	12.9[4]	9.1	28.1	41.3	4.3	4.1
Unemployment level (%)	1994	15.7	3.1	10.4	16.0	10.8	14.5
Industrial production	1994 (1993=100)	104	102.2	103.9	111.9	102.9	102.4
R&D scientists and engineers (FTE) per 1 000	1989	11.3[5,6]	8.5	4.1	na	5.6	1.7
labour force	1992	na	3.9	2.6	2.7	2.7	1.3
Students at	1989	157 861	na	100 868	505 727	164 507	na
tertiary level	1992	195 447	116 560	117 460	584 177	235 669	66 002
Females (%)	1989	52	na	51	59	na	na
	1992	57	44	51	56	47	48
Academic teachers at	1989	20 752	na	16 319	65 917	11 696	na
tertiary level	1992	21 976	14 798	17 743	60 783	18 123	9 351
Student : teacher	1989	7.6	na	6.2	7.7	14.1	na
ratio	1992	8.9	7.9	6.6	9.0	13.0	7.0

na: no data available.

1. Purchasing power parity.
2. 1990.
3. 1990-93.
4. 1993.
5. Bulgarian Academy of Sciences only.
6. 1985.

Sources: UNESCO, *Statistical Yearbook*, 1994; *Monitoring European Integration – The Impact of Eastern Europe*, CEPR Annual Report, 1990; *National Accounts Statistics: Main aggregates and detailed tables 1991*, UN, 1993; *Statisticka Rocenka Slovenskej Republiky 1993*, Bratislava, 1994; *Statisticka Rocenka Ceske Republiky 1994*, Prague, 1994; *Statistical Yearbook of Hungary 1994*, Budapest, 1994; *Rocznik Statystyczny 1994*, GUS Warsaw, 1994.

the objective long-term perspective, this was not necessarily a negative factor in all situations.

Secondly, there was the inefficiency of the old-new, new and new-old governmental structures which were not able to carry out long-term strategic thinking related to the development of science in Central Europe. No consistent vision of scientific and industrial policies was developed and implemented. The governmental structures were not able to resist two types of pressure paralysing the power to design appropriate policies:

- The populist pressures pushing the spiritual and material position of scientists down to a level very seldom experienced in the history of Central Europe.
- The primitive vision of the neoliberal ideology promoting the false view that market forces alone would create a new model of science, contrary to the theoretical and pragmatic experience of the Organisation for Economic Co-operation and Development (OECD) countries.

A third main barrier was the lack of strategic thinking and holistic perspective on the part of the great Western political and financial establishments, which were not able to promote the design and implementation of the new model of science in Central Europe. This does not mean that we underestimate the great panorama of activities of the numerous international organizations and institutions that are such a positive force in the Central European landscape of scientific transformation. There is no doubt, however, that in this panorama short-term limited activities are considered more important than long-term strategic programmes.

THE SITUATION IN 1995

According to the recent report prepared for the European Union, the system of higher education and science in Central Europe in 1995 has the following features:

- It is a system representing a 'cohabitation' of elements of the new and old orders. New solutions come up against large patches and islands of old institutional patterns, and the general level of coherence of the system is relatively low. The new finality of the system is generally accepted – at least it is claimed so. As regards motivation, the role of the old mentality is still very important. The dilemma – excellence versus mediocrity – has generally not yet been solved.
- The system is functioning in a situation of financial restrictions and difficulties, generating a shrinkage effect in many fields. However, certain successes in the creation of new financial foundations can be recognized.
- The system is a patient bleeding from external and internal brain drain which threatens to remove certain strategic links from the most advanced fields of research and teaching.
- The system has an already diseased structure dominated by old and older generations. The dearth of young, dynamic scientists is a growing phenomenon (European Commission, 1995).

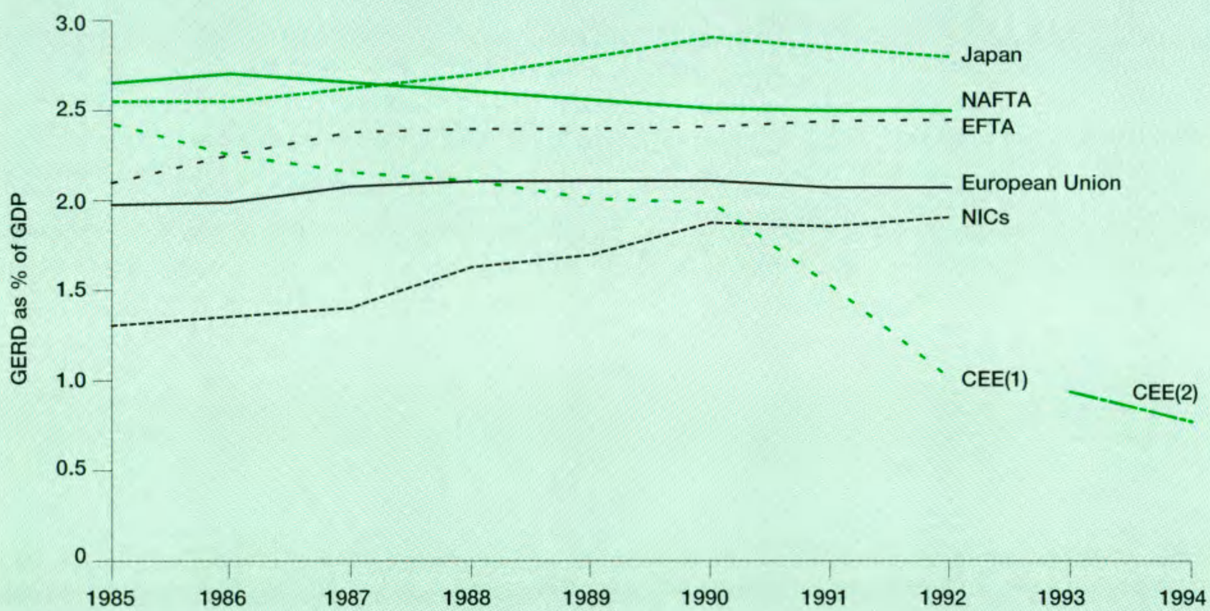
Such a diagnosis does not mean that the system has lost its power of survival and transformation, only that the balance of transformation for the years 1989-95 has not been very successful, as a result of both subjective and objective factors (see Table 1).

In short, our starting point for the crucial decade 1996-2005 is lower than might have been expected according to the optimistic scenarios. The vital first step in recovery has to be a reversal in the negative trends of research and development (R&D) intensity and gross expenditure on R&D (GERD) (see Figures 1 and 2).

THE OLD AND NEW INSTITUTIONS

The positive side of the years 1989-95 is largely related to the creation of new institutions and agencies responsible for the development of science, especially at

FIGURE 1
TRENDS IN R&D INTENSITY



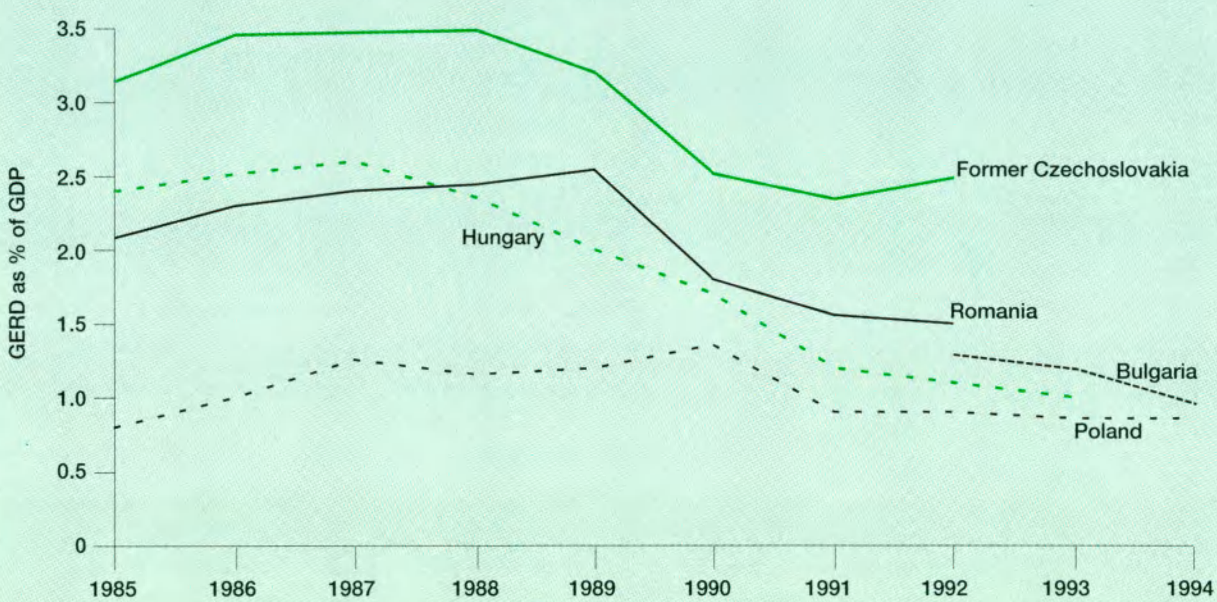
NAFTA – Canada, Mexico, USA
EFTA – Austria, Switzerland, Finland, Iceland, Norway, Sweden
European Union – Belgium, Denmark, Federal Republic of Germany, Greece, Spain, France, Ireland, Italy, Luxembourg, Netherlands, Portugal, UK
NICs – Hong Kong, Republic of Korea, Singapore, Chinese Taipei
CEE(1) – Bulgaria, former Czechoslovakia, Hungary, Poland, Romania, Russian Federation, Ukraine
CEE(2) – Bulgaria, Czech Republic, Slovakia, Hungary, Poland, Romania

Sources: *European Report on Science and Technology Indicators*, EC, 1994; various national sources.

the national level. These institutional changes have been well documented and analysed in a pioneering and comprehensive series of publications developed by the Institute for Human Sciences in Vienna (1993-94), and activities of the institutions have been described by Frackowiak (1994) and Imre (1994). The new legislation for higher education and science as created by the respective parliaments and governments should also be mentioned as a positive asset in this context.

The new institutions and new legislation have created inducements to inject the spirit of competition into the research system. Peer review, the objective competitive evaluation of projects submitted for financing, is a very positive innovation in R&D, and an adaptation of the scientific community to the general patterns of behaviour characteristic of the competitive society slowly emerging in Central Europe. Of course, the peer review system also has some weaknesses, and this is especially evident in smaller countries where everyone knows everyone else.

FIGURE 2
TRENDS IN R&D INTENSITY FOR INDIVIDUAL CENTRAL EUROPEAN COUNTRIES



Sources: *European Report on Science and Technology Indicators 1994*, EC, 1994; various national sources.

THE TRANSFORMATION OF HIGHER EDUCATION

The process of the transformation of the system of higher education in Central Europe during the period 1989-95 was slower and less efficient than originally expected. There are three things that might explain this phenomenon:

- the low priority assigned to higher education by the political elites and governments;
- the paralysing climate of shrinking financial resources;
- the excessive power of collective bodies such as senates and faculty councils. In practical terms, these bodies reduce the decision-making powers of university rectors and deans below the necessary minimum, even as regards current management, let alone strategic long-term solutions.[2]

In this depressing landscape, there are, however, some islands of successful transformation to be seen. In Central Europe a new system of private higher education is in the process of rapid development. We find a new range of relatively small or medium-sized

2. We share the value judgement expressed in TERC: 'As far as the problem of schools' self-government is concerned, the majority of responders in all four countries believe that too much power was transferred to collective bodies (senates, departmental faculty councils and institutes' scientific councils). Directors', rectors' and deans' executive powers are too limited.' S. Amsterdamski, TERC, vol. 5 (Institute for Human Sciences, 1993).

schools – especially in the fields of economic, legal and managerial sciences. Most important are various types of business school responding to the growing needs of private enterprise.

International organizations and foundations are promoting the development of new institutions of higher education. Just two examples may be mentioned: the Central European University in Prague and the extension of the College of Europe (Brugge) in Warsaw. However, this activity is still relatively limited in comparison with the great potential demand as seen in the long term.

The most important task, however, is to transform the existing academic institutions. There are three dimensions to this transformation:

- what might be described as the 'spiritual' transformation – the internalization of the competitive approach by both professors and students;
- the adaptation of teaching curricula to the new demands engendered by scientific, technological and economic progress;
- material transformation – the rapid modernization of the technical equipment of the universities.

Even from a pessimistic viewpoint, the achievements of the years 1989-95 are not to be underestimated. However, the tasks for the next decade are immense. The system of higher education needs to be developed rapidly in both quantitative and qualitative terms. At present, the student community in Central Europe is too small in comparison with other regions in Europe and with respect to the demands of the economy and society.

THE TRANSFORMATION OF THE ACADEMIES OF SCIENCES

Academies of sciences were created in the more important academic centres in Central Europe in the 19th century. Their development was continued and they were expanded during the years 1918-39 when all the Central European countries were independent states.

These academies were developed following the general European pattern. This natural evolution was destroyed, however, in the late 1940s and early 1950s when in all the Central European countries the traditional academies were liquidated and in each country a new academy of sciences was created: basically an institutional copy of the Academy of Sciences of the USSR.

However, during the years 1949-89 this Soviet pattern was modified in each country, according to the positive or negative pressures of the national political environment. We can perhaps mention just two examples – the positive liberal change in the Polish Academy of Sciences after 1956 and the negative totalitarian change in the Czechoslovak Academy of Sciences post-1968. The Romanian Academy of Sciences proved to be a special case, with both negative and positive dimensions.

In the first stages of democratic transformation after 1989, those in radical circles expressed the view that the academies ought to be liquidated because of their sin of Soviet origin. It is fortunate that this extreme proposition was not implemented and that the academies were able to survive the historical storm and start on the difficult road of transformation. It is to be regretted that the process of transformation of the academies in the years 1989-95 has been rather slow and inefficient – with the possible exception of the Czech Academy (Illner, 1994).

In any reflection of a comparative nature, three questions are especially important:

- To what extent was it possible to liquidate the huge bureaucratic machinery created during the old regime when an academy was *de facto* the ministry of science? The Polish example indicates that a very large part of this machinery has survived, even if the function of the Ministry of Science is performed by the State Committee for Scientific Research

TABLE 2
SCIENTIFIC PUBLICATION AND PATENT 'OUTPUT' PERFORMANCE OF CERTAIN CENTRAL EUROPEAN COUNTRIES

	Year	Former Czechoslovakia	Hungary	Poland
Number of publications	1992	4 586	2 795	5 844
World ranking (total number of publications)	1981-92	21	26	17
Growth in number of publications (1981=100)	1992	120	110	128
Growth in mean citation rate per publication	1988-92/ 1981-85 (%)	12	3	9
Patent applications filed by residents and non-residents	1991	5 934	9 950	8 817
Number of patents granted in USA	1991	47	966	106

Sources: *Scientific Citation Index 1981-1992*, Institute for Scientific Information, Philadelphia; US Patent Office.

which has, of course, created its own bureaucratic machinery. We consider that in the Czech Academy the old bureaucratic machinery was totally, or almost totally, liquidated.

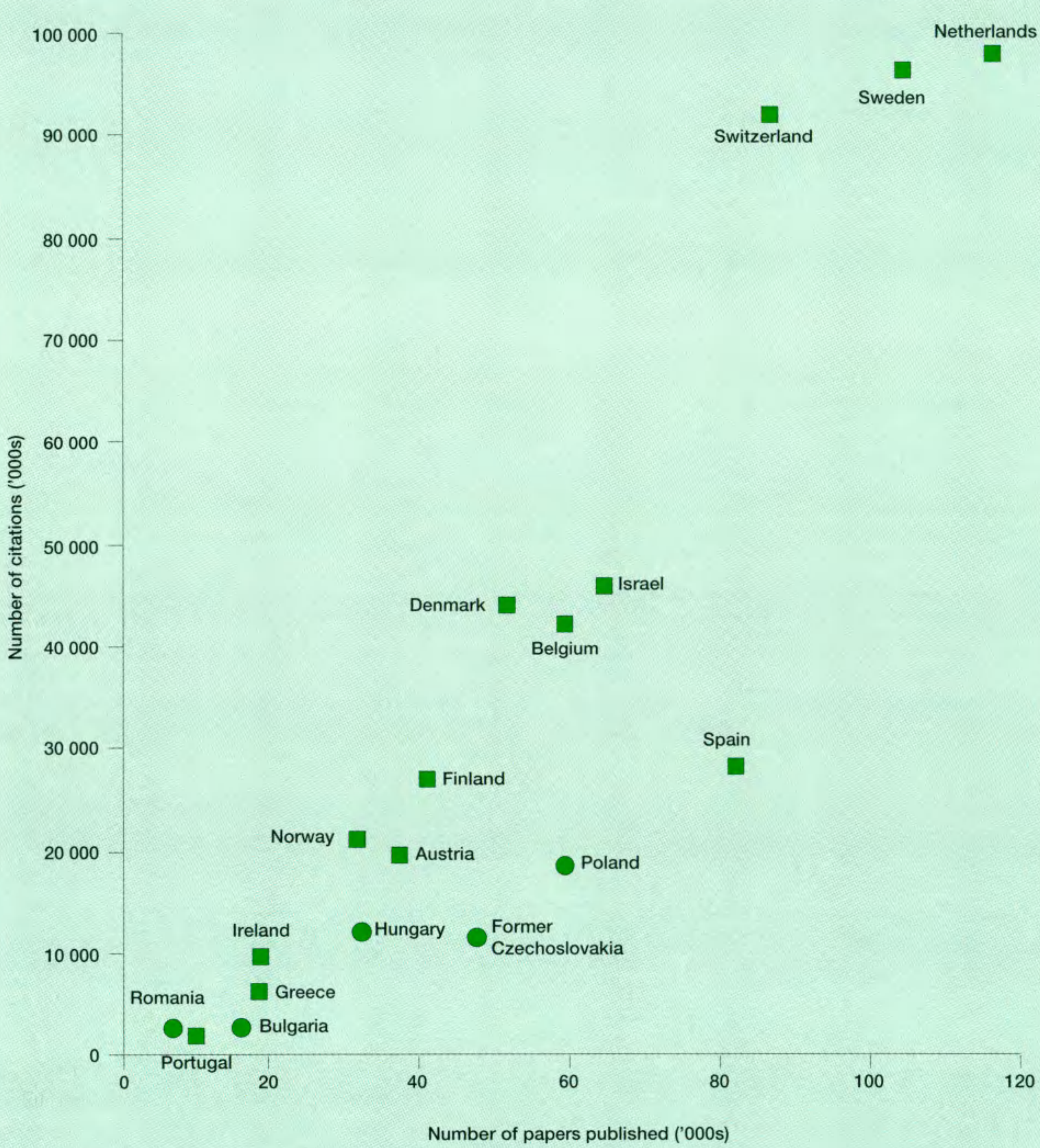
- To what extent has the academy – as a corporation of, by and large, the most eminent scholars – survived the test of the very profoundly changed political and systemic conditions? The principle of continuity, justified by objective or semi-objective standards, has been used as the argument for maintaining an unbroken succession in the Polish and Hungarian Academies.

- To what extent should the institutes of the academy – which represented in most cases a very high level of academic performance in the field of basic research seen in the perspective of global science – offer, after certain adaptation, very good conditions for a new successive stage of development? (It is not clear, however, whether this development should be kept within the present institutional pattern or a new pattern be created following the French (*Centre national de la recherche scientifique*) or the German (*Max-Planck-Gesellschaft*) experiences.)

THE TRANSFORMATION OF THE R&D SYSTEM

The system of real socialism gave rise to a very large and generally inefficient research and development infrastructure. This was represented mainly by vast networks of institutes and laboratories managed directly by the sectoral machinery of the centrally managed state

FIGURE 3
TOTAL NUMBERS OF S&T PUBLICATIONS AND CITATIONS FOR SELECTED EUROPEAN COUNTRIES, 1981-92



Source: *National Science Indicators 1981-92*, Institute for Scientific Information, Philadelphia, 1993.

economy. It succeeded in receiving a much larger share of the centrally allocated resources than did the system of the academies and higher education.

The transformation processes of 1989-95 have served to reduce this legacy of real socialism: something that could be seen as a positive phenomenon and as an unavoidable verdict of history. There is, unfortunately, a very dangerous trend in that the liquidation of the old R&D system is also destroying many valuable elements of the old system that were not totally rotten. What is more important is that this process of destruction is not being counterbalanced by the rapid creation of a new R&D system. Instead it is emerging very slowly because of the lack of coherent science and industrial policies designed and implemented since 1989, and a reluctance on the part of the new private entre-preneurship to promote research and development. With respect to the latter, one recently published comment on the situation in Poland is striking: 'We know for example that in 1992 the private sector's share in GDP creation was 47.2%, its share in total industrial employment was 55.7%, and its share in employment in integrated enterprise R&D units (altogether 45 500 persons) was... 9%' (Kwiatkowski, 1994).

A third reason for the slow creation of a new system is the reluctance of the transnational corporations and other foreign businesses to maintain and develop R&D units in their enterprises in Central Europe.

The creation of an R&D system adapted to the internal conditions of each country and to the European and worldwide challenges of the 21st century is one of the most urgent developmental problems to be solved in Central Europe.

THE SCIENCE OF CENTRAL EUROPE ON THE GLOBAL SCENE

There has been a long tradition of Central European science on the global scene. The example of Copernicus is arguably the most noteworthy. On the other hand, it must be said that the countries of Central Europe have had a poor record in terms of Nobel Prizes awarded.

The performance of real socialism has been a mixed one. In the field of natural and technical sciences the support of the state was relatively strong, and of course in this context, the role of the Soviet military industrial complex has to be mentioned. In the field of social sciences and humanities there was a significant difference between the relatively liberal experiences of Poland and Hungary and the hard-line policies implemented in Czechoslovakia, Bulgaria and Romania.

The transformation stage of the years 1989-95, contrary to initial expectations, has not led to an improvement in the ranking of Central Europe on the world scientific scene (see Table 2 and Figure 3). On the contrary, the financial difficulties and the effects of the brain drain have clearly diminished the competitive power of Central Europe and shifted the Central European countries to lower rankings on the international scale.

This shift, however, is not dramatic and an improvement in this field can be realistically expected in the near future, if a more positive scenario for the development of science is put in place in Central Europe.

CONCLUSIONS

Three concluding remarks are perhaps appropriate. First, the process of transformation of science in Central Europe is well advanced, although both the endogenous and exogenous barriers diminishing the efficiency of this process have proved greater than originally anticipated. The crucial decade 1996-2005 must see the construction of a new model of science in Central Europe – a model well related to that created by the European Union which, at the beginning of the next century, will most probably incorporate the Central European countries as full members. The transformation of science in Central Europe is necessary not only for science itself – but as an essential factor in the transformation of the whole economy.

Secondly, the monitoring, explanation and guidance of the emergence of the new model of science in Central Europe are creating an urgent need for large-scale empirical comparative studies to analyse the whole process in a rigorous methodological framework. In these studies, not only will the general features of the transformation process in Central Europe be properly defined but also the specific characteristics of each country. Discussion on the latter has not been possible in this chapter due to limitations of space.

Finally, in all activities related to the transformation of science in Central Europe there is a need for reliable and well-organized statistical data – prepared in the framework of the methodologies developed by the Organisation for Economic Co-operation and Development (OECD), the European Union and UNESCO. The quality of the statistical information on S&T in Central Europe is currently low and the process of change in the relevant information systems has, in the years 1989-95, been very slow and inefficient. A comparison of the statistical information on Central Europe with the quantity and quality of that presented in the *European Report on Science and Technology Indicators* (European Commission, 1994) should serve as an inducement for the statistical offices in Central Europe to be much more efficient in the future.

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Bogdan Kacprzynski was Professor at the University of Warsaw and associated with its European Institute for Regional and Local Development. A graduate of the Technical University of Warsaw in telecommunication, he developed a broad, interdisciplinary interest in the mathematical, technical and social sciences, and latterly in science and technology policy matters. He published five books and over 200 scientific papers in his career.

Professor Kacprzynski's participation in this chapter was to prove his last written work before his sudden and untimely death in the spring of 1995.

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The Commonwealth of Independent States

LEONID GOKHBERG

The break-up of the Union of Soviet Socialist Republics resulted in fundamental changes in the objectives of national economic, social and political development. These are being reflected in the transformation of the institutional structure of the economy, rapid growth in the private sector, conversion of the military industries and gradual integration of the former Soviet countries into the international economy, at both regional and worldwide levels. This transition to a market economy and democratic society in the countries now making up the Commonwealth of Independent States (CIS) is having a profound impact on their scientific communities, and science has become one of the prime concerns of their national policies.

These processes are generally taking place under conditions of economic recession, inflation, severe budget deficit, a worsening social situation and political instability. In these circumstances, and against the background of science and technology systems inherited from those of the former Soviet Union, special care is needed to avoid the erosion of science in the newly independent countries, and to provide the market-oriented research and development (R&D) base required for future economic and social revival.

The Commonwealth of Independent States

An agreement to found the Commonwealth of Independent States (CIS) was signed in Minsk on 8 December 1991 by the leaders of Belarus, Russia and Ukraine. Recognition of the fact that the sovereign states formerly making up the USSR shared a will to implement political and economic reforms made it clear that there was a need radically to revise relations between the former Soviet republics. Only internationally accepted principles of mutual acknowledgment and respect for national sovereignty, equality and non-interference could become a basis for a new type of unity. Main areas of coordinated activity have been strategic armed forces, foreign policy, a common market, transport and communications, protection of the environment, migration policy and the prevention of crime.

Armenia, Kazakhstan, Kyrgyzstan, Moldova, Tajikistan, Turkmenistan and Uzbekistan joined the CIS upon signing the protocol on 21 December 1991 in Alma-Ata. Azerbaijan was officially admitted to the Commonwealth on 24 September 1993, and Georgia became a member in December of the same year. With its present boundaries the CIS accounts for 99.2% of the former Soviet Union's land area and for 97.2% of its population.

The CIS member countries have shown a move towards an association with an effective means of integration, as opposed to the earlier tensions. The CIS Summit Meeting on 21 October 1994, in Moscow, had as a principal objective stronger cooperation as a precondition to overcoming crisis and to providing economic growth. In this connection agreements were adopted on, amongst other things, a free-trade zone and common political, scientific and cultural activities.

THE COLLAPSE OF THE SOVIET R&D MODEL

The extensive growth in the numbers of R&D institutions and related investment in the USSR up to the late 1970s had allowed the development of an extremely large R&D base, bigger, in relative terms, than that of most of the industrially developed countries. The substantial concentrations of highly qualified human resources provided the foundation for some impressive achievements in basic research and the development of military-oriented technologies.

However, even by the beginning of the 1980s, the R&D sector had to a large extent lost its dynamism, as reflected in the decline of growth rates of both input and output R&D indicators. Thus after 1985-86 employment in this sector declined in the USSR in general and in most former republics in particular.

These negative trends, which have only fully come to light recently, are deeply rooted in the special nature of the Soviet R&D model.

The legacy of centralization

The strong centralization of R&D and the uneven distribution of research institutions over the USSR that had developed over the decades have imposed differences between the CIS countries in terms of scientific capacity and specialization. Regional distribution of R&D has been concentrated in those developed regions with intensive economic activity, and this is true both for the USSR and Russia.

Thus almost 58% of R&D institutions, 54% of higher educational establishments, 68.5% of postgraduate students, 66.7% of R&D personnel and over 72% of the total R&D expenditure in the USSR were to be found in Russia.[1] For example, Russia's contribution to R&D in terms of expenditure was five times greater than that of Ukraine, which ranked second in this regard, and the gap was much greater in the case of other states. The shares of Belarus, Kazakhstan and Uzbekistan were in the range 1.3-3.4%, and the R&D efforts of Kyrgyzstan, Tajikistan and Turkmenistan did not exceed 0.15-0.2% of the USSR's total (Table 1).

TABLE 1
PERCENTAGE DISTRIBUTION OF MAJOR R&D INDICATORS OF THE FORMER USSR BY COUNTRY, 1991[1]

	R&D institutions[2]	*R&D personnel*	*R&D expenditure*
USSR	100.0	100.0	100.0
CIS	97.6	97.4	97.7
Russia	57.8	66.7	72.2
Other CIS countries	39.8	30.7	25.5
Belarus	4.4	3.6	3.4
Kazakhstan	3.5	1.6	1.3
Moldova	1.4	0.8	0.7
Ukraine	17.0	17.9	15.8
Caucasus countries	5.1	3.0	1.6
Armenia	1.6	0.9	0.5
Azerbaijan	1.8	0.9	0.6
Georgia	1.7	1.2	0.5
Middle Asia countries	8.2	3.7	2.7
Kyrgyzstan	0.8	0.3	0.2
Tajikistan	0.9	0.3	0.2
Turkmenistan	0.9	0.3	0.2
Uzbekistan	5.6	2.8	2.1
Baltic countries	2.4	2.6	2.3

1. The individual figures may not add to the totals because of rounding.
2. Excluding Lithuania.

Source: Centre for Science Research and Statistics.

1. Here and elsewhere, unless specifically cited otherwise, data are from the Centre for Science Research and Statistics, Moscow.

The uneven geographical distribution of R&D has been influenced by political exigencies and historical tradition, and the impact of these factors cannot be overestimated. The network of Academy of Sciences research institutions and leading higher educational establishments inherited from the former Soviet Union was concentrated mostly in large cities – the capitals of the former union republics and the centres of the administrative regions. This is a function of the concentration of governmental bodies and of administrative power under the Soviet system, as well as of the higher living standards found in the big cities. The first institutions of the Academy and the universities were established, for example, in Moscow, St Petersburg, Kazan, Kharkov, Kiev, Lvov and so on. The major centres of scientific and technological information, libraries and archives were also located in the main cities.

The USSR Academy of Sciences was organized as a highly centralized administrative body, while republican academies existed as affiliations serving to enhance the political prestige of the republics and to provide a platform from which local economic and social problems might be addressed. In order to create a stock of researchers quickly for the national republics special action was undertaken, including creating quotas for entry into Russian universities without competition and having lower requirements for dissertations.

Russia's R&D and higher education services used to be the source of progress in science and technology (S&T) in many fields in the other newly independent states, and the break-up of the USSR has threatened their further development. Access for citizens of other republics to the elite universities and technical colleges in Russia has been reduced. At the same time a number of advanced basic research institutes, industrial R&D units and special facilities of importance (such as the space launching site in Baikonur and the Crimean and Armenian observatories), now find themselves located outside the Russian Federation and, as a result, the R&D capacities of newly independent states in some research areas do not necessarily respond to the demands of their national economies. On both these counts it is reasonable and mutually beneficial to transform the relationship that was of a 'centre–periphery' nature into equal and long-term S&T cooperation between CIS countries.

Common infrastructures

The R&D sectors of the CIS countries are marked by basically common institutional structures and organizations that are greatly influencing their transformation during the period of transition.

The institutional R&D infrastructure in the USSR was organized in line with the general principles of the Soviet administrative system; like other legal entities, R&D institutions were attached to specific branch ministries. Generally, R&D in the CIS countries is carried out within four groupings (see Figure 1).

Due to the technocratic orientation of R&D, the industrial R&D sector played a dominant role in the USSR, both in terms of numbers of R&D institutions (64%) and researchers (66%), as well as in the value of R&D (75.8%).[2] This distribution of R&D capacities by sector is still largely in force in the CIS countries, with some local variation.

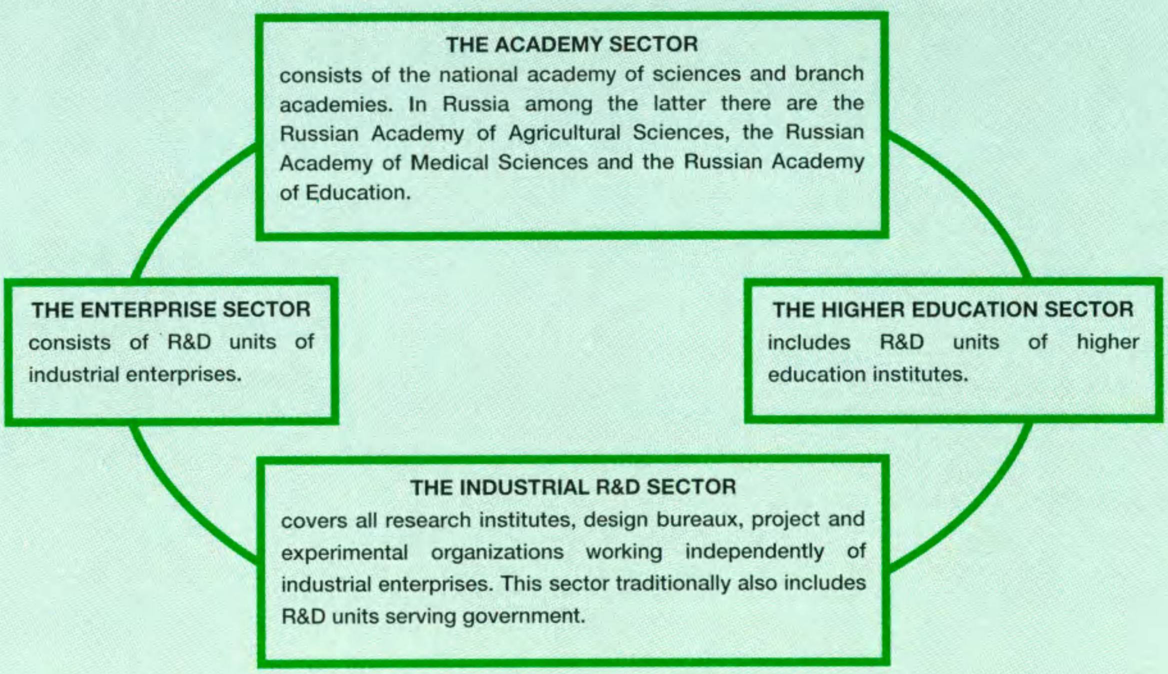
Traditionally, sectors of R&D performance have specialized in different types of activity. Thus, basic research has been concentrated in the academy sector, in a limited number of R&D institutes, mostly serving military industries, and also in some elite higher education institutes.

In contrast to the majority of learned scientific academies in Western countries, the CIS academies have been entrusted with the administration of networks of R&D institutes separated from industry and higher education. They have inherited a hierarchical structure typical of Soviet branch ministries.

The former system created barriers between the

2. Data for 1990. The value of R&D includes current expenditure on R&D and profits obtained by R&D institutions from R&D activities during the year.

FIGURE 1
R&D: SECTORS OF PERFORMANCE IN THE CIS COUNTRIES



academy, the universities and industry, and the artificial separation of science from higher education served to damage the social status and the scientific authority of universities. R&D in the higher education sector came to be considered, at least by academy researchers, as second-rate.

There were large, elite universities and a few higher engineering colleges training personnel for military R&D that were exceptions to this rule. These were much better provided with resources and enjoyed the status of prestigious education and research centres. Such institutions traditionally enlisted the help of academy researchers in their teaching and worked together with the research institutes in graduate programmes.

The industrial R&D sector, which by definition was mainly engaged in applied R&D, became oversized. Each branch ministry or department tended to establish its own network of R&D units, many of which primarily served the administration rather than enterprises. The most advanced R&D in industry was devoted to military applications.

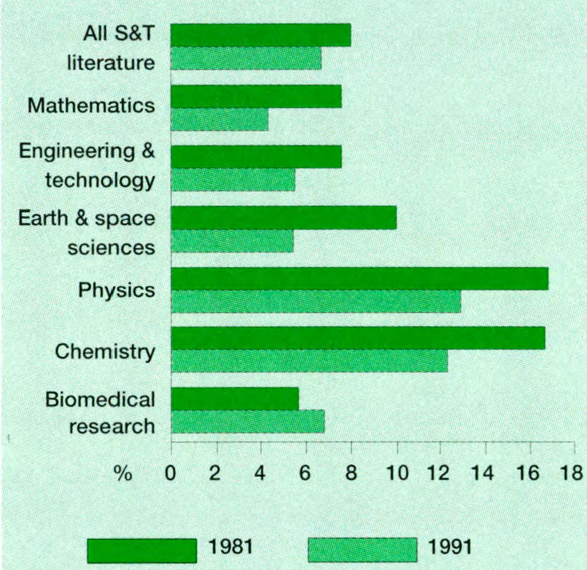
For economic and institutional reasons the enterprise sector was relatively weaker than the others, being generally able only to adapt innovations to production in order to modernize current products. It was characterized by the lowest rates of R&D indicators.

As a whole R&D in the CIS countries existed within a framework of rigid administrative subordination of research-performing units, leading to strong group interests and inertia which are proving difficult to overcome in the current transition period, though this needs to be done.

Isolation and priorities in science

Over a period of decades, science and technology in the USSR was developed under the heavy pressure of ideological and political dogmas, and was judged primarily from the viewpoint of the political prestige and military potential of the nation. With the economic isolation of the USSR prior to the Second World War and the very limited international cooperation during the Cold War that followed, a serious gap emerged in science. The USSR's R&D strategy was a broad one, covering all fields of science and technology. In some areas, the domestic objectives of the scientific programmes repeated those being set abroad. This caused ineffective resource spending instead of gains that might have been made from international collaboration and, at the very least, led to slight lagging behind the international scientific community. Thus despite significant achievements in space research, nuclear physics and so on, the contribution of the USSR to world S&T literature decreased over the period 1981-91 from 8.0% to 6.7% (Figure 2).

FIGURE 2
SHARE OF USSR IN WORLD S&T LITERATURE



Source: National Science Board, 1993.

The absence of a flexible international trade policy linked with economic demand led to spending on the development and manufacture of products that were uncompetitive on the world market (personal computers, consumer electronics and pharmaceuticals). Opening up frontiers to imports resulted in a rejection of domestic products, and related R&D efforts have therefore been of little practical use.

Political considerations influenced the setting of research priorities according, first of all, to military objectives, while biology and medical sciences, cybernetics, the social sciences and humanities were beset by ideological limitations and the lack of resources.

The academy sector and military-oriented R&D enjoyed the highest priority. They were supported by large-scale state action implemented in various forms – direct budget funding, the centralized supply of imported research equipment, the construction of modern buildings for the most prestigious institutes, hard-currency appropriations for missions abroad and the purchase of scientific literature and officially approved privileges in salaries and even in the duration of holidays. Within the Academy of Sciences and the defence research units there was an extensive social infrastructure for the provision of housing, medical and childcare services, foodstuffs and consumer goods, whereas researchers in other sectors were deprived of such things. Consequently, employment in those two sectors was much more prestigious than that in the civil industrial R&D institutes or in the higher education sector. This in turn helped to attract skilled personnel, and recognized research schools were created in many fields of science and technology.

All these factors resulted in severe inertia within the whole research organization and a desire to maintain obsolete institutional structures. This has hampered timely reaction to changes in the environment and has obfuscated the need for urgent structural transformation.

GENERAL TRENDS DURING THE TRANSITION PERIOD

The S&T base of the CIS countries is currently undergoing a major transformation in order to adjust to market conditions. The former USSR states are developing their own systems according to national political and socio-economic objectives and each is following individual specific means of restructuring. They nevertheless share certain features with regard to the conversion of their R&D systems due to their shared past experiences.

Trends in R&D potential have been influenced by the overall economic situation in the CIS countries. The principal macroeconomic indicators (Table 2) paint an all-too-clear picture of the current economic recession. Between 1991 and 1994 the gross domestic product (GDP) of the CIS countries fell by 39% and industrial production by 44%. Consumer prices increased 1 600-fold on average, with the rate even higher in some countries. The standard of living of the population has sharply reduced, with millions of people finding themselves below the poverty line.

According to present estimates, the governmental budget deficit in the Commonwealth countries in 1994 ranged from 5% to 21% of GDP, e.g. in Russia it was approximately 13% (Statistical Committee of the CIS, 1995). Continued investment in unprofitable sectors, e.g. agriculture and military industry, needs to support more and more social programmes, and failure to make payments on the part of enterprises has made the situation even more complicated. In many cases economic difficulties have been exacerbated by political crises, ethnic conflicts and military clashes.

TABLE 2
RATES OF REAL GROWTH OF KEY ECONOMIC INDICATORS IN THE CIS COUNTRIES
(1994 as % of 1991)

	GDP	Industrial production	Capital investment	Consumer price indices
Armenia	40	50	4	807 100
Azerbaijan	46	53	113	236 900
Belarus	65	68	47	320 700
Georgia	25	24	3	–
Kazakhstan	57	52	29	561 500
Kyrgyzstan	52	42	23	58 200
Moldova	48	51	15	90 900
Russia	61	56	39	74 200
Tajikistan	51	48	33	76 400
Turkmenistan	150[1]	66	–	423 600
Ukraine	60	62	43	1 079 000
Uzbekistan	83	98	52	112 900
CIS average	61	56	41	160 400

1. 1993 as % of 1991.

Source: Statistical Committee of the CIS (1995).

R&D FUNDING

All these problems have meant that neither governments nor enterprises are able to continue R&D funding at the earlier achieved levels. This has been reinforced by the following factors:

- discontinued centralized all-Union science and technology programmes, capital investment and supplies and the rupture of R&D contracts between different states' institutes and enterprises;
- increasing burdens on national budgets and, consequently, decreases in real terms in the proportions of government appropriations on R&D;
- lack of interest in long-term investment on the part of enterprises, and a near-absence of industrial demand for R&D;
- relatively low prestige of employment in R&D and poor remuneration, especially when compared with the business sector.

TABLE 3
VALUE OF R&D BY CIS COUNTRY (CALCULATED AT CURRENT PRICES)

	1989[1]	1990[1]	1991[1]	1992[1]	1993[2]
Armenia	222.9	231.1	168.5	479.1	2 300.4[1]
Azerbaijan	117.0	140.7	194.3	974.5	1 074.2
Belarus	853.0	862.0	1 097.8	7 480.4	94 636.5
Georgia	213.4	177.2	–	–	–
Kazakhstan	321.2	326.0	425.2	2855.1	91.7
Kyrgyzstan	45.3	59.0	49.0	321.5	10.8
Moldova	142.9	182.3	219.1	1 129.0	12.3
Russia	18 348.5	18 371.3	23 269.6	173 448.6	1 445 416.1
Tajikistan	57.0	50.2	55.1	226.3	1 529.5
Turkmenistan	47.0	45.8	65.3	631.2	61.4
Ukraine	3 675.9	3 649.7	5 079.2	61 832.7	1 695 559.0
Uzbekistan	389.5	379.6	665.8	3 400.3	334 272.3

1. Million roubles.
2. Million national currencies.

Source: Centre for Science Research and Statistics, national statistical agencies.

The CIS countries are consequently experiencing a drastic downsizing of their R&D base, an unprecedented event in the history of science and technology in the 20th century (Freeman, 1994).

Problems of R&D funding need to be examined in the context of the further decline of research in national priorities as expressed in the decreasing indicators of R&D effort. Growth in R&D value (Table 3) has not been sufficient to compensate for accelerating inflation. Measured at constant prices, R&D expenditure in the CIS during the period 1991-93 fell by 40-60% per country.

In Russia R&D expenditure calculated in accordance with OECD standards reached some 1 313.6 billion roubles in 1993 (Table 4). Its average annual growth in 1989-91 was slightly ahead of that of the USSR for the same period (12.8% as against 11.7%), but still lower than the inflation rate. Expressed in constant 1989 prices, R&D expenditure in 1993 was equivalent to only 24.8% of that in 1990.

Growth in R&D expenditure has lagged behind that of the main macroeconomic indicators. The share of R&D expenditure (GERD) in GDP in Russia declined from 2.03% to 0.81% between 1990 and 1993. In terms of the OECD data for this indicator, Russia fell below the median in the group of countries with low R&D potential such as Ireland, Iceland, Spain and New Zealand. In most other CIS countries the R&D percentage of GDP was even smaller (Figure 3).

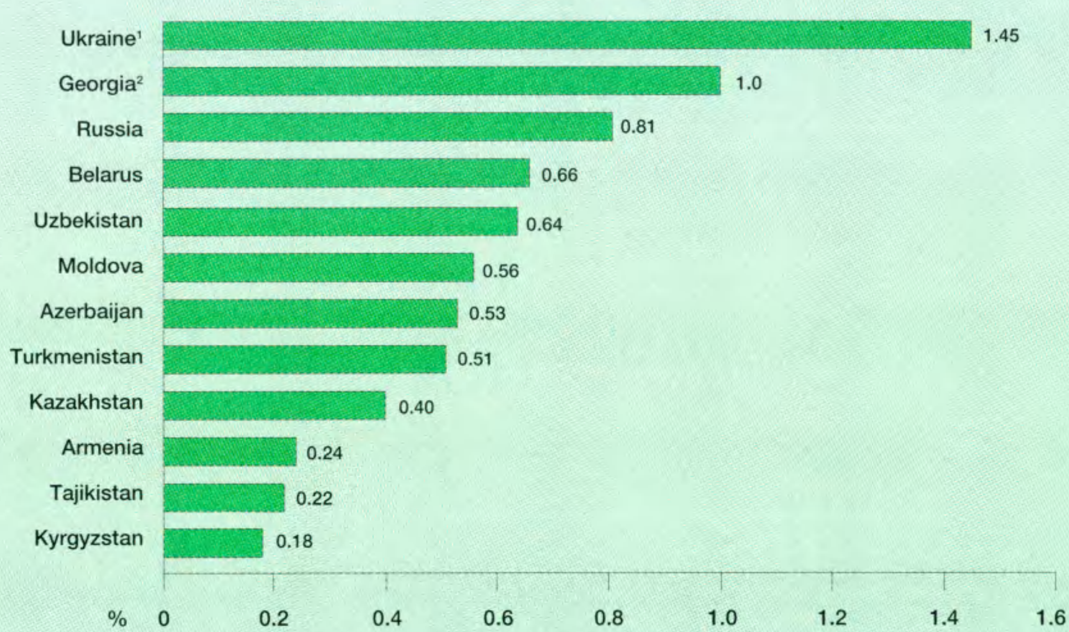
In spite of substantial institutional transformation, the government budget still remains the largest source of R&D funding and almost the only one for basic research. The extremely centralized system of R&D financing is being maintained, even as the pace of economic reform has quickened. The states have simply not succeeded in attracting private investment in science and technology. Meanwhile, the governments do not yet really know what they want from R&D, and unfortunately R&D spending is not considered a high priority in current national structural policies.

TABLE 4
R&D EXPENDITURE IN RUSSIA[1]

	1990	1991	1992	1993
Total R&D expenditure:				
current roubles, millions	13 077.7	19 990.7	140 590.8	1 313 556.7
1989 roubles, millions	10 898.1	7 196.1	2 350.4	2 699.9
As % of GDP	2.03	1.54	0.78	0.81
In US$, millions[2]	23 945.0	20 168.2	9 569.9	6 412.4

1. Calculated by the author in accordance with OECD standards.
2. Calculated on the basis of annual purchasing power parities.

FIGURE 3
R&D EXPENDITURE (GERD) IN THE CIS COUNTRIES AS A PERCENTAGE OF GDP, 1993



1. This seems to be overestimated. According to the data of the Ukrainian Academy of Sciences, the figure was 0.7% in 1993.
2. 1990.

Source: Calculated by the author using data from national statistical agencies.

CIS countries differ in the share of appropriations on R&D within the total government budget (Figure 4). According to this indicator, they can be classified into four subgroups reflecting the relative importance of R&D in national priorities:

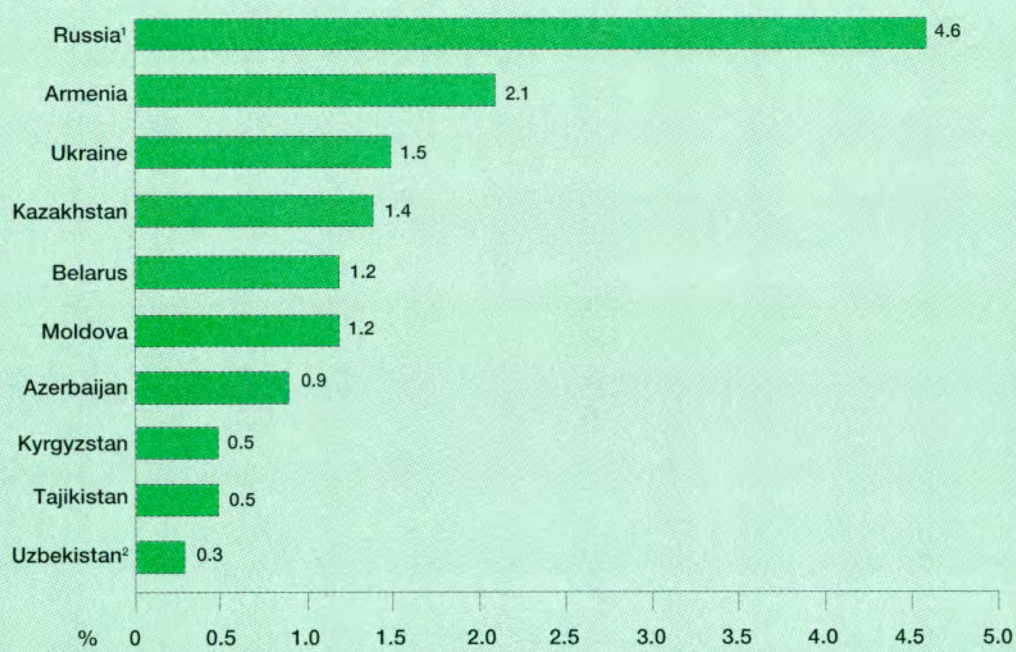
- relatively high priority (Russia);
- middle-level priority (Armenia, Ukraine, Kazakhstan);
- relatively low priority (Belarus, Moldova, Azerbaijan);
- negligible priority (Kyrgyzstan, Tajikistan, Uzbekistan).

Generally speaking, the so-called 'residual principle' of allocation of budget funds for R&D, predominant in the former Soviet Union (Gokhberg and Mindeli, 1993: 12), is still in force in the CIS countries.

As a result of increasing short-term economic pressures, there are signs in all sectors of waning interest in R&D on the part of enterprises. But the fact that national scientific academies continue to be supported from state budgetary funds, taken together with the reduced industrial demand for applied research, has been the main reason for the relative growth in basic research: in most states of the CIS the share of domestic R&D expenditure increased 1.5- to 2-fold on average in 1989-93 (Figure 5). In terms of this indicator the CIS countries are now close to the

FIGURE 4

R&D APPROPRIATIONS AS A PERCENTAGE OF GOVERNMENT BUDGET EXPENDITURE BY COUNTRY, 1993



Note: Figures not available for Georgia and Turkmenistan.

1. R&D appropriations on civil R&D in Russia in 1993 constituted 2.5% of the total government budget.
2. 1991.

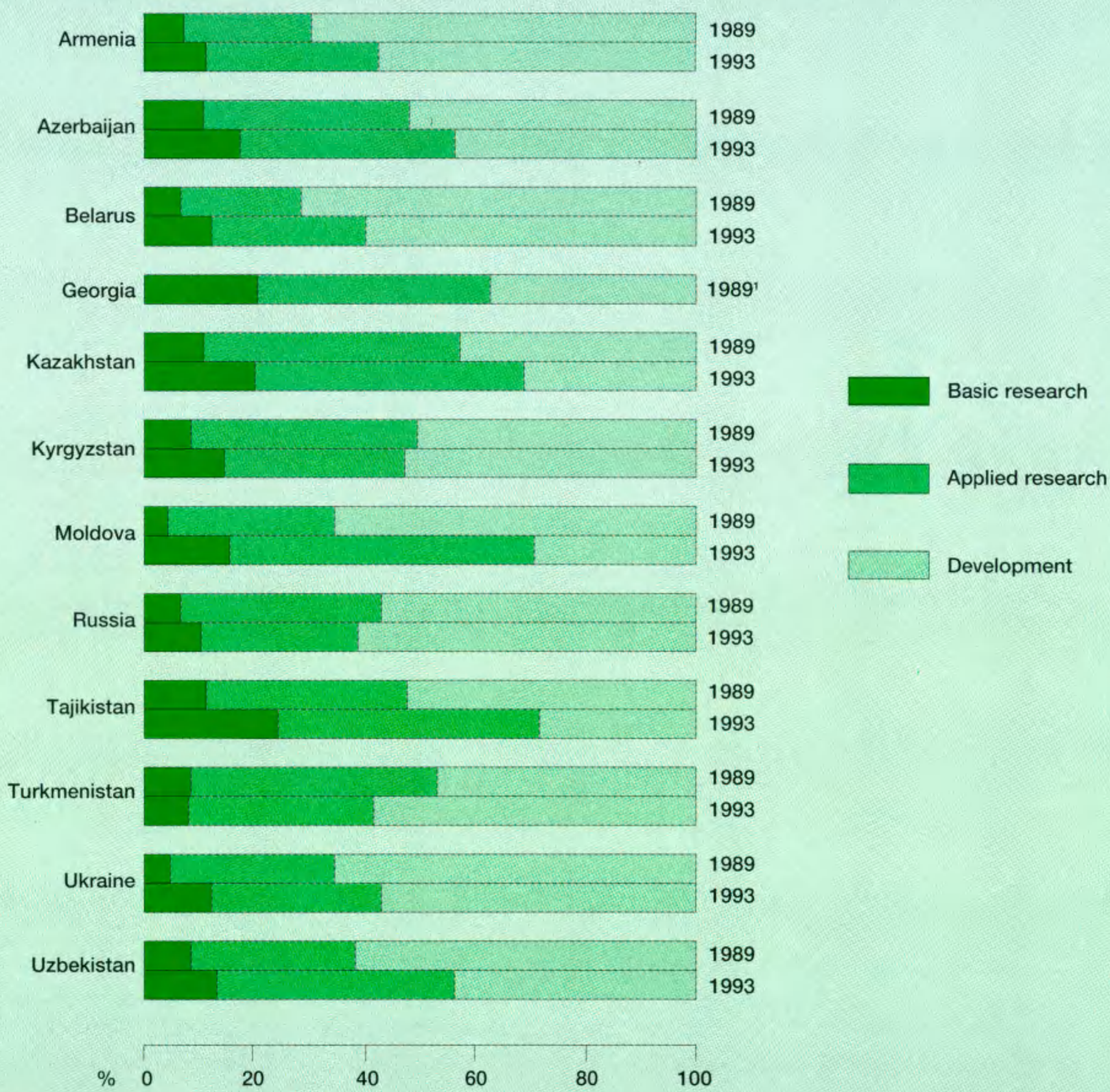
Source: Centre for Science Research and Statistics, national statistical agencies and scientific academies.

leading industrial nations: 13% in the UK and Japan, 14% in the USA, 19% in Germany and 23% in France (National Science Board, 1991: 344).

Under unstable financial conditions the academic institutes are being forced to implement projects which do not meet the objectives of their research. For

FIGURE 5

PERCENTAGE DISTRIBUTION OF R&D EXPENDITURE IN THE CIS COUNTRIES BY TYPE OF ACTIVITY



1. 1993 figures not available.

Source: Centre for Science Research and Statistics, national statistical agencies.

example, the academies of science in some CIS countries provide a significant number of S&T services to other research units and enterprises: the Academy's share in the respective national total in 1993 reached 8% in Azerbaijan, 9.7% in Uzbekistan, and as much as 18.3% in Moldova and 19.6% in Kazakhstan. In this respect the Centre for Scientific Research and Statistics (CSRS) sample survey at the Russian Academy of Sciences gives a picture which, in fact, is characteristic of other CIS countries. Thus, according to the survey data, in 60% of the Academy institutes some 10% of the research does not correspond to the profile of their activity; in the remaining 40% the level is approximately 25%.

As far as the higher education sector is concerned, the CIS states each pursue their own different policies. In Azerbaijan, Kazakhstan, Moldova and Russia universities are set to increase their participation in basic research in both absolute and relative terms. This reflects budget support for basic research at universities, whereas higher education colleges of engineering are funded to a lesser degree. At the same time, higher education institutions in Belarus, Ukraine and Uzbekistan are generally more oriented towards applied research in an attempt to satisfy the needs of industry.

The industrial R&D sector itself has suffered to the greatest extent from the market changes. Decreasing industrial demand for R&D in the long term has influenced the declining role of this sector in performing R&D. In Russia, for the first time for a long period, the contribution of industrial R&D institutions to national R&D expenditure decreased, from 90.3% in 1991 to 86% in 1993. The share of basic research in the R&D totals in the major industries is within the limits of 0.4% to 1.7%, but among these industries there are branches determining technological progress (chemistry, electrical machinery, instrument-making, etc.). In Belarus industrial research institutes and design organizations have lost 60-70% of their contracts.

The implementation of structural changes needed to prevent further deterioration of the R&D base is being hampered by high inflation. In 1991-92, along with increases in material costs, there was rapid growth in salaries and labour-related costs (indexation and compensation payments, increased social security contributions and the introduction of retirement tax). Depreciation rates for machinery and equipment were also raised. As a result, research institutes sometimes simply found themselves with no funds for current spending.

Efforts to compensate for the sharp growth in the cost of living by increasing wages have proved unsuccessful, and were, in any case, made at the expense of other items of expenditure, notably material ones. In Russia in 1992 aggregate wages rose to 38% of current R&D expenditure (48.9% if social security contributions are taken into account).

The deficit of foreign currency and the fall in the exchange rate of the rouble and other CIS national currencies have reduced imports of research equipment and the acquisition of foreign S&T literature to nearly zero. Many advanced capital-intensive research institutes with expensive equipment and modern premises have found themselves in a most difficult situation. The absence of the necessary instruments and materials has sometimes caused the termination of research projects.

CONVERTING DEFENCE RESEARCH

The major CIS countries (Russia, Ukraine, Belarus and Kazakhstan) are involved in the conversion of the defence industry and allied R&D, and this has had an influence on the decline in industrial R&D totals. In those states some 70-75% of R&D totals were devoted to defence applications at the beginning of 1990s.

It is impossible not to be struck by the reduction in the share of R&D within total military expenditure. Thus between 1989 and 1993 this figure decreased from 19.8% (USSR) to an approximate 7.2% (Russia).

The defence R&D base has thus contracted more sharply than military production *per se*. The chaotic, unplanned nature of conversion is threatening the continued existence of many large research institutions of the defence complex and is exacerbating the breakdown of links between R&D and industry.

The largest part of the USSR defence R&D base was located in Russia; on the break-up of the Soviet Union some 74% of the total number of defence R&D-performing units were concentrated there. In terms of expenditure, these units performed 88% of the USSR's defence R&D (Centre for Science Research and Statistics, 1993*a*).

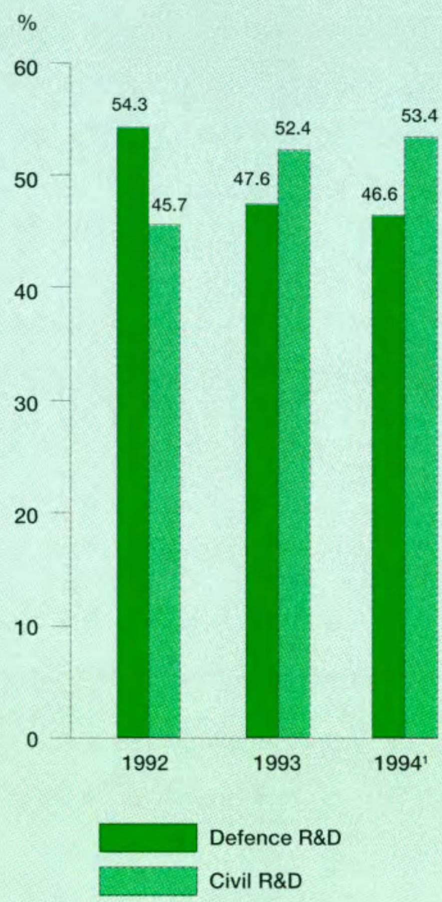
Appropriations for defence R&D in Russia were multiplied by more than 57 at current prices between 1991 and 1993 to reach 711.7 billion roubles. At constant prices this indexation was insufficient: in 1993 the value of defence R&D did not exceed 4.1 billion roubles at 1991 prices. Nevertheless, by international standards, Russian R&D remains excessively militarized. Defence-oriented programmes still account for some half of the total R&D expenditure (in Ukraine, according to the Ukrainian Centre for Studies of Science and Technology Potential and History of Science, it constituted 31% in 1992). Therefore, the share of civilian R&D expenditure in 1993 was only 0.44% of the Russian GDP, compared to 1.3% in Italy, 1.7% in the UK, 2.0% in France, 2.1% in the USA and 3.0% in Japan (OECD, 1994*a*).

Redirection of defence R&D is reflected in changes in the programmes performed by the defence R&D institutions (Figure 6). They compete with the weaker civil R&D units for funding and contracts, and seem to have started replacing the latter in the market.

Priority areas for the civil application of defence research capacities in Russia are as follows:

- civil aviation and space;
- new materials and technologies;
- information and telecommunications systems;

FIGURE 6
R&D EXPENDITURE AT R&D INSTITUTIONS OF THE RUSSIAN DEFENCE INDUSTRY BY OBJECTIVE (IN PERCENTAGES)



1. Estimates.

Source: State Committee on Statistics of the Russian Federation (1995).

- computers and instruments;
- consumer goods;
- equipment for agriculture, food, textile and clothing industries, trade and public catering;
- power engineering and transport equipment;

- medical equipment;
- equipment for environment protection.

But growth in civilian R&D activity within institutes in the process of conversion is not able to compensate for the decline in defence programmes. Transforming the profile of defence research units demands time and additional funding. In any case, cut-backs at industrial R&D institutes usually have oriented basic research as the first victim, and its rate of decline is twice as steep as that of the R&D of defence institutes as a whole. Finally, even in the defence sector, the share of basic research in 1994 was estimated by the Russian State Committee on Statistics as being only 1.1% of aggregate R&D activity.

HUMAN RESOURCES IN R&D

Faced with a lack of any effective means of social protection, galloping inflation and difficult consumer conditions, personnel in R&D institutions cannot be retained with existing wage bills. In those CIS countries with large R&D potentials (Ukraine, Belarus and Kazakhstan) salaries in the R&D sector were 5-7% less than those in the national economy as a whole in 1993, and in Russia in particular they were only 76.7% of the 1994 average. In banks, private firms and joint ventures salaries are two- to three-fold higher. Against a background of growing opportunities for business and the revival of private property, this makes entrepreneurship more and more attractive for qualified and enterprising people. Many of the high-level managers of large businesses (banks, industrial groups, joint ventures, insurance firms, etc.) are holders of doctoral degrees.

Outflow to the business sector has become a dominant feature in the decline of R&D employment in the CIS countries. Between 1991 and 1993 this outflow reached 20-40% (per country), and national figures ranged from Azerbaijan's 3% and Turkmenistan's 8%, to 54% for Armenia, 53% for Uzbekistan and 44% for Belarus. Historical variations in numbers of R&D personnel in the newly independent states have been aggravated by these uneven staff decreases. Thus, by the

TABLE 5
R&D PERSONNEL BY CIS COUNTRY

	Total (researchers, technicians, support staff)			Researchers only		
	1991	1992	1993	1991	1992	1993
Armenia	22 816	20 863	10 596	12 699	14 129	7 106
Azerbaijan	22 701	19 036	21975	14 800	12 236	14 549
Belarus	90 999	58 278	51 181	50 963	33 685	30 474
Georgia	30 345[1]	–	–	20 719[1]	–	–
Kazakhstan	40 879	29 145	30 383	22 417	17 248	17 435
Kyrgyzstan	8 705	7 405	5 897	4 912	4 163	3 826
Moldova	19 351	14 317	12098	10 585	8107	6 828
Russia	1 677 784	1 532 618	1 315 008	878 482	804 043	644 881
Tajikistan	6 892	5 002	4 248	3 493	2 777	2 267
Turkmenistan	7 971	6 517	7 355	4 485	3 663	4 272
Ukraine	449 782	380 797	345 849	243 019	208 058	189 445
Uzbekistan	70 405	45 732	33 685	31 202	22 039	15 724

1. 1990.

end of 1993, a 310-fold gap was reached between Russia and Tajikistan (Table 5).

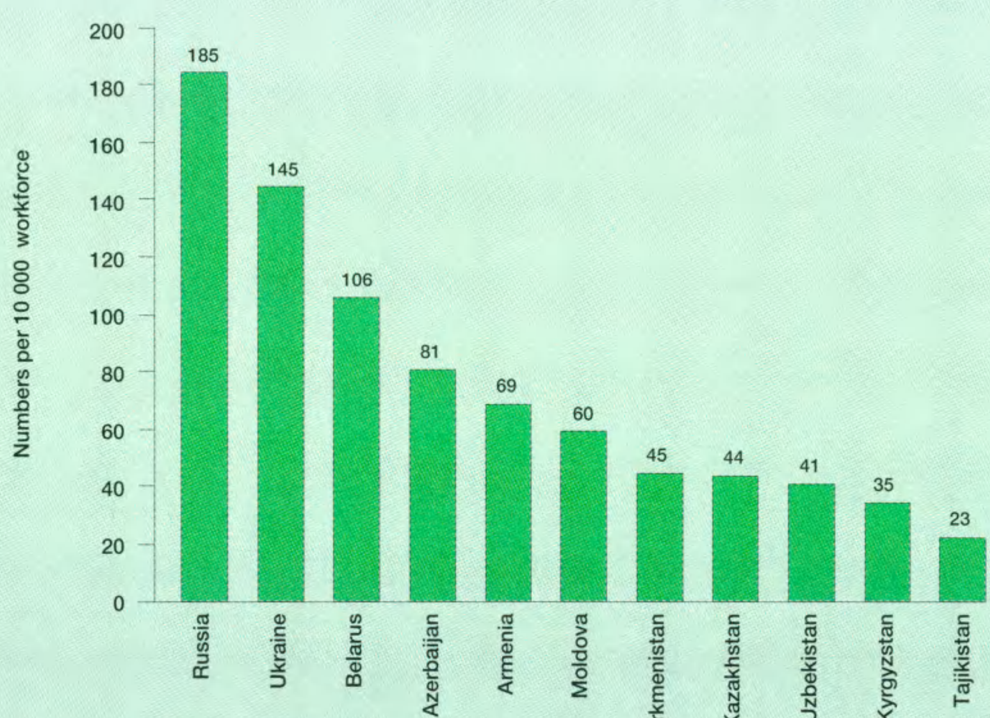
In spite of declining R&D personnel numbers, Russia, Ukraine and Belarus still have a relatively high level of R&D employment as a proportion of the national employment totals compared with other CIS countries (Figure 7).

Generally speaking, the national scientific academies have been less affected by the large-scale reduction in personnel compared with other R&D sectors. The academy sector's R&D personnel in Russia fell by 9% between 1991 and 1993, as opposed to 33% in industrial R&D institutions, and in Ukraine the figures were 9% and 28% respectively. Azerbaijan and Turkmenistan academies were notable for a growth in staff engaged in R&D.

This relatively favourable picture is the result of the academies' policy of preserving human resources for basic research. It seems that the majority of scientists do not intend to leave their academy, because they consider research to be their life's work and have already achieved some worthwhile scientific results. According to the Centre for Science Research and Statistics sample surveys in research institutes of the Russian Academy of Sciences, almost 85% of academic researchers questioned planned to continue their careers at the Academy, whereas only 2% of the respondents expressed an intention to leave.

Employment within the academies is attractive to researchers because of the opportunities for combining their primary job with secondary employment in the business sector. Analysis of data from CSRS sample

FIGURE 7
SHARE OF R&D PERSONNEL BY COUNTRY, 1993



Source: Centre for Science Research and Statistics.

surveys highlights the growth in the proportion of the body of Academy researchers employed part-time in private firms – from some 35% in 1992 to 45% in 1993. Twenty-four per cent of the Academy researchers questioned also worked as university teachers and 11% in industrial R&D institutes.

This factor to some extent explains the healthy statistical appearance of employment in the academy sector. In order to preserve research units, heads sometimes allow their staff members long-term unpaid leave, or transfer them to half-time jobs. This gives researchers an opportunity to keep their nominal posts, whilst in practice working elsewhere. Inevitably, however, this has a negative influence on the volume and quality of the actual research work carried out in the academies. It is clearly difficult to combine employment in basic research with commercial activity, and this is why basic research is more seriously threatened by this kind of development.

In the absence of strategic measures aimed at bringing about urgently needed structural changes, the downsizing of R&D establishments and the formation of an S&T labour market are widespread. Most personnel leaving R&D institutions do so voluntarily. Thus in Russia redundant staff accounted for only 8% of the total outflow from the R&D sector in 1993.

The overall reduction in R&D personnel has especially involved technicians and support staff (with the exception of Azerbaijan). This can be explained by the drive to reduce overhead expenditure and by cutbacks in R&D equipment. Not surprisingly, a reduction in the effectiveness of researchers and a deterioration in working conditions have resulted. At the same time, representatives of the two 'suffering' categories adapt themselves more easily in the new economic situation.

In the Russian Federation during the period 1989-94 the total personnel employed in the R&D institutions of the defence industry decreased by 40%, and included in their number were many talented researchers. Re-orientation of research towards civilian purposes was accompanied by changes in the distribution of R&D personnel between defence and civil programmes; according to existing estimates, 48.4% of personnel in conversion R&D units were employed in defence programmes versus 51.6% in civil ones. However, the opportunities for them to secure new jobs are very limited; only 25% of personnel disengaged from defence R&D actually received offers within the same organizations (*Economist*, 1995; State Committee on Statistics of the Russian Federation, 1995).

The decisive element in this human resources issue is the reduced inflow and growing outflow of young researchers, linked with the low interest of young people in R&D careers. There has thus been a marked tendency towards the ageing of R&D personnel, due to the reduction of the 30-40 year age group. At the beginning of 1994, 37.6% of all R&D personnel in Russia were under 40, but for highly qualified researchers this proportion was lower – 2.8% and 19.9% among doctors and candidates of science respectively. As many as 40.8% of doctors of science are of retirement age. The average age of Russian Academy of Sciences members – academicians – is in the range 63 (economists) to 72 (international relations specialists). Even in the most dynamic fields of S&T such as nuclear physics, informatics and biology, the average age of academicians is 68-69. In other CIS countries the situation is similar, e.g. in Belarus 34.5% of doctors of science are over 60 years old.

The system of remuneration does not encourage younger researchers. Those aged 30-34 years receive salaries which are some 84% of the average, and researchers below 30 years of age earn just 73% of that figure. According to our estimates, researchers over 60 years of age are paid 50% more than those in the age bracket 35-44. To help counter this in Russia, state scientific fellowships have been offered since 1994 to talented young researchers and postgraduate students, as well as to prominent scientists with outstanding research achievements.

Against the general background of reduced R&D employment in the CIS, the picture of highly qualified researchers looks different. Thus the number of doctors of science engaged in R&D on a full-time basis grew between 1991 and 1993 in Turkmenistan by 75%, in Kazakhstan by 30.3%, in Ukraine, Belarus and Moldova by 16-18% each and in Russia by 12.5%. This was related to simplified procedures for defending dissertations and reduced requirements, as well as to the continued high prestige attached to doctoral degrees. By contrast many candidates of science, being younger and more dynamic, have left the R&D sector.

The uneven decreases in categories of R&D personnel and the absolute growth in the numbers of doctoral researchers have led to an increase in the share of personnel with advanced degrees by 3-6% in certain states during the period 1991-93. Only in Armenia and Kyrgyzstan have numbers of scientific degree holders declined both absolutely and relatively.

The migration of scientists

Political, economic and social changes in the CIS countries since the disintegration of the USSR have brought about substantially new trends in international migration. In this connection two major flows of scientists and engineers should be considered: between the former Soviet Union states and to other foreign countries.

Migration of R&D personnel between the countries of the former Soviet Union is largely influenced by social factors. Various political and ethnic conflicts in the newly independent states have caused a significant proportion of the so-called Russian-speaking population to move to Russia. This has involved skilled personnel (engineers, teachers, qualified workers, etc.), including some who had graduated from Russian universities or technical colleges earlier, but had received jobs in other former Soviet republics. Very often they come to Russia as refugees, along with elderly people and others of less socially protected categories.

Of the CIS countries, Russia is the only one with a net inflow of migrants from other republics of the former USSR, the total number of immigrants reaching 0.8 million in 1994. Kazakhstan, Kyrgyzstan and Uzbekistan have become the largest donor countries, whereas Tajikistan, Georgia and Azerbaijan occupy second place in this respect. Migration from this latter group is largely the result of political and military conflicts.

In many cases national or ethnic problems also affect populations of native nationalities and they too participate in immigration flows to Russia. It must be said that a negligible number of immigrants have found jobs related to S&T in Russia.

S&T researchers, representing as they do the highest rung of the R&D ladder, are feeling the influence of the international migration of scientists and engineers and other kinds of external 'brain drain'. For decades the former Soviet Union, a country ranked third in the world in terms of population, had no part in international migration. Since the emigration procedure was simplified, however, within the framework of human rights policy action undertaken in the USSR in 1985-86, the country has become open to migration.

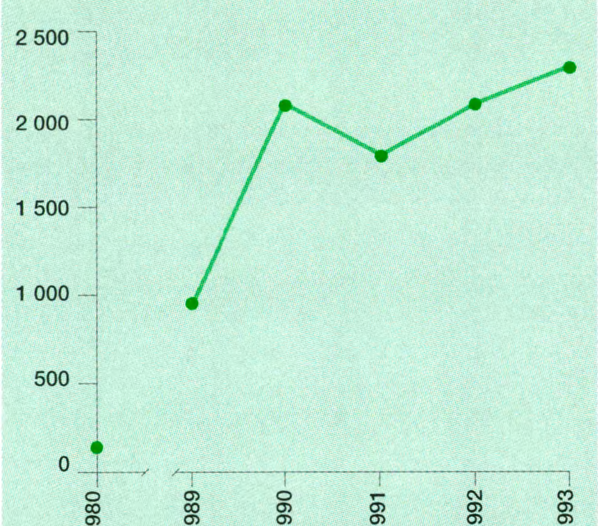
External 'brain drain' is particularly prevalent in Russia and Ukraine, which are becoming increasingly open to international economic and S&T cooperation. The participation of Russian and Ukrainian scientists and engineers in international S&T projects, the creation of companies with foreign links, foreign-owned subsidiaries and joint ventures, has meant the entry of these countries into the international S&T labour market. It is hardly surprising, therefore, that scientists and engineers dissatisfied with the social and political situation in their home country, with low welfare standards and poor opportunities for implementing their research ideas, look for a job or a grant abroad. This often results in international migration for a temporary job or for the completion of education, and ultimately in emigration.

A recent study conducted by the Centre for Science Research and Statistics, using data of the Ministry of Internal Affairs of the Russian Federation, made possible a statistical evaluation of the numbers of R&D personnel who have emigrated from Russia (Figure 8).

Emigrants accounted for only 0.6% of the total outflow of staff from the R&D sector. This seems to indicate that the process of 'brain drain' has not yet taken on serious dimensions. The greater part of the flow of emigration is driven by ethnic factors, as previously; the labour market still plays only a subsidiary role.

The Russian Academy of Sciences (RAS) lost 508 researchers to emigration in 1991-92, a figure representing some 0.8% of its total. According to the Ukrainian Centre for Studies of Science and Technology Potential and History of Science, 160 researchers with advanced degrees previously employed at the Ukrainian Academy of Sciences emigrated in 1990-92, or approximately 1% of their number.

FIGURE 8
EMIGRATION OF R&D PERSONNEL FROM RUSSIA



Source: Centre for Science Research and Statistics, 1995.

Of the RAS emigrants, 13.2% worked in general physics and astronomy and 11.6% in biochemistry, biophysics and the chemistry of physiologically active compounds. Most of the emigrants held the degree of candidate (55.9%) or doctor of science (16.2%). Half of the researchers who emigrated were under 40 years old. Israel and the USA dominated the list of receiving countries, accounting for 42.1% and 38.6% respectively of the total number of emigrants.

At the same time contract R&D jobs overseas are gaining in importance, particularly with the most highly skilled and competitive specialists, often those with recognized scientific track records. If they do not return, this form of 'brain drain', though not significant in scale, may have substantial qualitative impact and represent a long-term problem for the development of science and technology in Russia. In 1991-92, 1 701 researchers of the RAS were working on long-term missions (of more than six months) or under contract abroad. As many as 60% of these were under 40 years old.

It is interesting to see how the various fields of science are represented in the list of RAS researchers temporarily working abroad. Mathematics leads (12.1%), followed by biochemistry and biophysics (9.2%), then nuclear physics (4.9%) and general physics and astronomy (4.1%). The majority of these researchers work in the USA (38.2%) followed by Germany (16.2%), France (8.9%), the UK (5.7%), Canada (5.2%) and Japan (4.1%).

S&T EDUCATION

In the USSR a wide network of higher education institutions had been established to nominally provide equal right of access to tertiary education for citizens of all the Union's republics. By the end of 1991 there were 951 such institutions with the total enrolment of 5 079 800 (including the Baltic States).

The disintegration of the Soviet Union resulted in a breakdown of the existing linkages and a need for division of labour in S&T education between the former Soviet Union countries. The CIS states were thus obliged to increase their own capacities in S&T education and the training of highly qualified specialists in order to meet national demands. All the CIS countries, with the exception of Armenia, have indeed managed to reinforce their national networks of public higher education institutions: some 40 new institutes were established in 1993 alone, including those providing training in economics (Kyrgyzstan 1, Moldova 1, Russia 1, Tajikistan 2 and Uzbekistan 1), law (Kazakhstan 2), industry and construction (Kazakhstan 2, Kyrgyzstan 5, Russia 4), agriculture (Russia 2, Ukraine 1), transport (Turkmenistan 1) and theology (Moldova 1). New universities of a general nature were opened in Kyrgyzstan (2) and Russia (3); military colleges and police academies were created in Belarus and Tajikistan. At the beginning of the 1993/94 academic year there were 999 higher education institutions in the CIS (Table 6).

It should be noted that higher education still enjoys high prestige among the people. Thus, despite the crisis, competition for places at universities and colleges has been relatively stable, and in Kyrgyzstan, Russia and Uzbekistan it has even increased since 1985.

The numbers of students per 10 000 population in most of the CIS countries are decreasing but for a few of them, such as Russia (Figure 9), Belarus, Georgia, Kazakhstan and Ukraine, at the 160-170 mark (Table 6), they remain comparable to those of some OECD countries (see OECD, 1994*b*, p. 52).

In the USSR higher education was directed towards the mass training of specialists. Part-time (i.e. evening) and distance education were therefore significantly oversized (representing up to 46% of the total higher education enrolment). Obviously, these forms of

TABLE 6
MAJOR HIGHER EDUCATION INDICATORS BY CIS COUNTRY, 1993/94

	Number of public higher education institutions	Enrolment ('000s)	Entrants ('000s)	Graduates ('000s)	Enrolment per 10 000 population
Armenia	14	46.5	4.2	12.1	124
Azerbaijan	23	94.3	13.6	18.8	127
Belarus	38	175.4	34.4	35.8	169
Georgia	23	91.1	12.5	14.9	168
Kazakhstan	68	272.1	54.6	49.1	161
Kyrgyzstan	21	52.3	11.3	10.0	117
Moldova	17	46.9	10.2	9.0	108
Russia	548	2 542.9	543.5	443.6	171
Tajikistan	22	69.0	16.8	13.2	123
Turkmenistan	11	38.9	7.8	9.2	89
Ukraine	159	829.2	170.0	153.5	159
Uzbekistan	55	272.3	28.7	63.0	123

Source: Centre for Science Research and Statistics; national statistical agencies.

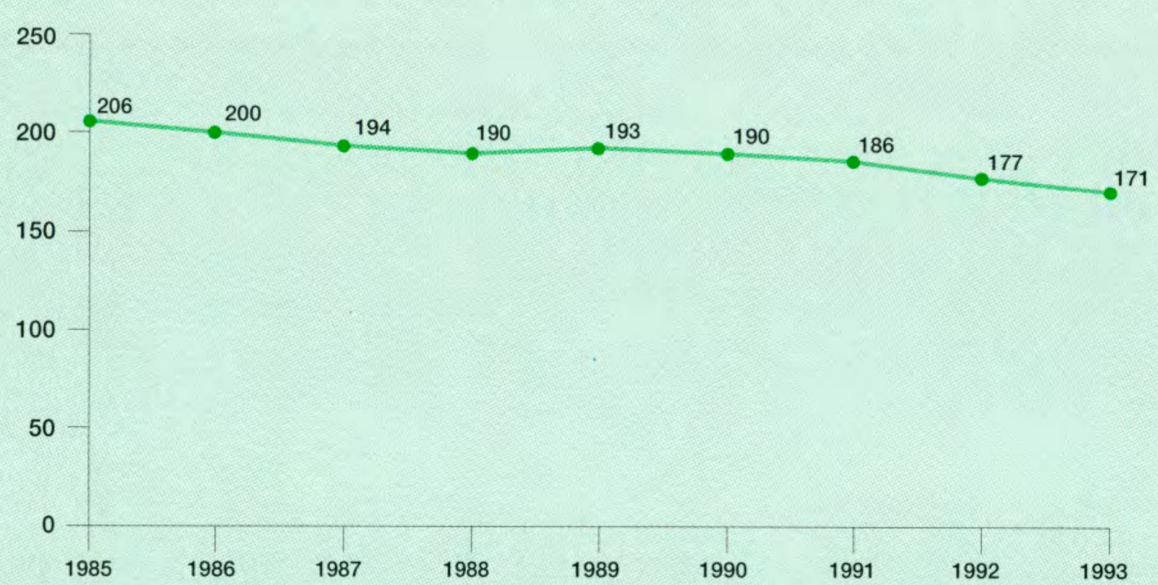
education cannot provide the required quality of training, and their reduction has caused an overall decline in the higher education student population in the CIS during the period 1991-93.

Entrances to part-time and distance higher education institutions declined sharply in all newly independent states (except for Tajikistan) during this period. Part-time courses decreased 4.2-fold in Belarus, 3.8-fold in Uzbekistan and by one-third in Kazakhstan and Russia. Armenia and Moldova discontinued evening courses at higher education institutions. For the moment, the highest shares of part-time students in higher education enrolment are in Azerbaijan (11%), Georgia (9%), Uzbekistan (8%) and Russia (7%). In certain countries there is still a high and growing proportion of distance education students, namely in Azerbaijan, Tajikistan, Georgia and Uzbekistan (31-37%).

Another important feature of higher education in the USSR was the priority given to engineering. Enrolment in higher education institutions of industry, construction, transport and communications accounted for approximately 42% of the total for the Union. On the other hand, the share of graduates in high technologies was quite small.

In spite of an absolute decrease in the numbers of entrants in the CIS countries, the different national priorities of the CIS countries have resulted in a number of fields of study in which actual growth in entrance numbers was achieved during the period 1991-93. In order to promote the development of domestic industry, construction and agriculture the Central Asian governments have brought about entrance number increases at related colleges. However in Russia, along with the new growth trends in entrances to higher education institutions of economics, law and

FIGURE 9
HIGHER EDUCATION ENROLMENT PER 10 000 POPULATION IN RUSSIA, 1985-93



Source: Centre for Science Research and Statistics.

agriculture, there is a still increasing interest in 'traditional' university education. Entrance figures for Russian universities have been steadily growing since the end of the 1970s, and this confirms the fact that university education in Russia continues to maintain its historically high prestige.

Five or six years ago engineering, medicine and agriculture were the most popular fields in the former Soviet republics, with economics and law being considered less prestigious. Since then, the demands of the labour market have changed, but an inflexible higher education system established under centralized planning has not had sufficient financial and managerial capacity to respond adequately. Thus the number of higher education graduates in engineering and medicine (including physical culture and sports) in the CIS increased by 14-15% (against the 11% average) in 1991-93, whilst that in economics and law decreased by 16%.

Due to discrepancies between the requirements of the labour market and the supply of graduates, in 1993 in Russia for example, 17.6% of graduates did not receive a job offer from employers via the higher education institutions, as had been the practice for decades. In addition, 25.7% of graduates turned down their offers, preferring to find better paid and more prestigious jobs for themselves, mainly in the business sector. Among these there were graduates of modern and broad subject areas needed by the market, i.e. 30-33% of all graduates in economics, humanities, natural sciences, radio engineering and telecommunications, computers and automated control systems.

With the present trends in higher education, further reductions are to be expected in the inflow of qualified personnel to R&D. In the USSR in 1976-80, the proportion of graduates intending to work as researchers was 6%, but this figure had fallen to 2% by 1986-90. In 1993 only 1 012 graduates started work at the Russian Academy of Sciences, compared with 3 300 in 1989.

In response to the new challenge created by the market transition and the present economic, financial and social difficulties, changes to the CIS higher education system are being focused on the following:

- The establishment of private universities competing with public ones. In Russia they numbered some 200 in 1993, but less than half – 78 – were officially certified as providing education to existing standards. Private universities accounted for 7.9% of the total number of higher education entrants in Russia in 1993.
- The gradual introduction of two university educational standards (equivalent to bachelors and masters degrees), and a revitalization of education programmes.
- Enhancement of a variety of education services, e.g. the establishment of paid full-time and part-time courses, the retraining of higher education diploma holders towards new professions and contracts for training within enterprises.

Postgraduate education

The postgraduate training of well-qualified S&T personnel in the CIS countries involves two levels of course, directed towards candidate and doctoral degrees. The last two decades have seen decreases in postgraduate training; over the period 1970-90 the total number of postgraduate students decreased by 7.3% in the former Soviet Union as a whole. The main reductions, e.g. in Russia, occurred in the fields of science connected with technology (engineering, physics, mathematics and chemistry), agriculture and economics, while growth was notable in medicine and the humanities.

Some signs of an increase in postgraduate enrolment were evident in most CIS countries in 1993. Only in Azerbaijan and Kyrgyzstan did the numbers of entrants decline, by 42-46%.

The effectiveness of postgraduate courses is usually low: only 12-20% of postgraduate students (by country) completed their candidate dissertation in 1993 (in Russia the figure was 24%).

The insufficient prestige of scientific degrees and low stipends do nothing to encourage postgraduate students to continue their education. The numbers leaving courses before finishing programmes in the CIS countries increased 1.2- to 2.2-fold in 1991-93, except for Russia and Belarus, where they did not change. Only a small proportion of graduates intend to follow a research career after taking postgraduate courses. The 1993 CSRS sample survey of postgraduate students at the major Russian universities and higher education institutes for engineering showed that only 8.8% of respondents hoped to work at the Academy of Sciences after completing their education, whereas 54.2% expressed an interest in joining the business sector.

Doctoral courses represent the ultimate stage in the training of S&T personnel, and they have been established at the leading research institutes and universities. In Russia in 1993 there were 452 institutions offering such courses, with an enrolment of 1 700. Some 34% of students in doctoral courses graduate with a doctoral dissertation. The Supreme Certification Committee of the Russian Federation confirmed 19 200 degrees (both candidate and doctoral) in 1993, compared with 35 100 in 1991.

POLICIES FOR S&T

Under the centralization policy prevalent in the USSR, all administrative bodies responsible for a common S&T policy (the USSR State Committee for S&T, the Presidium of the Academy of Science, the Ministry of Defence and branch ministries) were located in Moscow. Particular republics did not usually have expertise in elaborating and implementing comprehensive S&T policies. Exceptions were made for republican and regional S&T programmes devoted to local applications and the semi-public management of local R&D infrastructures under the auspices of the scientific academies of the republics.

Since gaining independence, the CIS countries have thus been faced with a need to develop national S&T policies. Most of the former republics, involved as they have been in drastic economic and societal transformations, have simply not been able to formulate proper S&T policies nor organize their implementation from scratch. After a period of uncertainty in this domain from 1991 to early 1993, it has now become generally accepted that S&T should not be maintained only as an inheritance from the USSR, but that these disciplines can serve as an important motor of economic and social development.

From late 1991 onwards the newly independent states began setting up national S&T policy institutions. These have taken various forms (Ministry of Science and Technological Policy in Russia; State Committees on Science and Technology in Ukraine, Azerbaijan and Uzbekistan; Ministry of Science and New Technologies in Kazakhstan; State Committee on Science and New Technologies in Kyrgyzstan; Ministry of Higher Education and Science in Armenia; etc.), but notwithstanding formal differences these agencies all have responsibility for the elaboration and implementation of governmental S&T policies.

In order to increase the authority of S&T policy making and its practical influence, high-level coordination bodies have been established in some countries. Among these are the Council on S&T Policy under the President of the Russian Federation and the Governmental Commission for S&T Policy headed by the Russian Prime Minister; the Commission for S&T Progress, Technological Development and Conversion under the Kazakhstan Cabinet; the Supreme Council on S&T under the President of Turkmenistan, etc. Where they exist, these councils are responsible for the development and evaluation of national strategies in S&T, priority measures and interdepartmental coordination. Such bodies include representatives of governmental agencies involved in S&T and scientific communities (academies, associations, etc.), as well as prominent scientists.

National academies of sciences have improved their legal standing and enjoy the status of the highest self-governing scientific institutions. In Russia and Ukraine national academies have been declared as non-governmental bodies, but in all the CIS countries they are almost wholly financed from government budgets. Academies have not undergone any major internal changes, and are currently trying to keep the administrative levers of control over research institute activities.

The necessary 'infrastructural' departments, such as patent agencies, certification committees responsible for approving scientific degrees, agencies for standardization and metrology, and so on, have also been established.

The main objectives of the CIS countries' national S&T policies currently include:

- maintaining national R&D potentials to provide a base for economic and social development;
- concentration of resources in priority S&T directions;
- development of a market environment and a legal basis for encouraging S&T and innovation;
- state support for the conversion of defence R&D;
- ensuring the development of basic research;
- integration into the world of S&T cooperation.

In forming new S&T policies, national authorities are trying to strengthen a goal-oriented approach to R&D budgeting which is considered to be a key prerequisite to restructuring the R&D system. Government S&T budgets in major CIS countries are in principle designed according to a common scheme. A larger part of the budget appropriations on civil R&D (up to 80% of the total in Russia and Ukraine) is allocated to national academies and branch departments for the subsequent financing of research institutes. The remainder is divided between national priority S&T programmes (14-18%) and the newly established foundations (2-6%).

The ratio of these two major parts of the civil R&D budget is of political importance. While the first reflects the will to continue maintaining a large number of research institutions, often without any visible output, the second is a step towards establishing a mechanism for government policy implementation under market conditions (however, in this context the determination of chosen priorities is an issue of the utmost importance). The basic allocations therefore reflect the degree to which the transformation of S&T policy is being carried out.

In Russia a significant share of budget appropriations on civil R&D allocated to government departments is directly devoted to the Russian Academy of Sciences. As a result of an increase in funding for priority programmes, this share dropped from 17% of the total in 1991 to 13.3% in 1994. Little wonder, then, that this policy meets with some resistance on the part of the R&D bureaucracy. Currently, whilst the Academy institutes are financed mainly from the federal budget or through the government S&T programmes, both of which are under the responsibility of the Ministry of Science and Technological Policy, the role of the Presidium in administering research units and redistributing budget funds does not meet the objectives of many institutes, particularly the larger ones.

Moreover, a growing proportion of funds intended to finance the R&D base of government departments is allocated within the framework of federal economic programmes, which include an R&D element. Among the foremost of these in Russia are the Federal Space Programme and the Civil Aviation Development Programme, which together account for 20% of the total budget appropriations on civil R&D, and programmes on electronics, agricultural machinery, ecological security and new medical equipment. Similar national economic and industrial programmes encompassing R&D also exist in Ukraine and Kazakhstan.

S&T PRIORITIES

As mentioned above, there exist specific S&T programmes representing national priorities, including basic research on new phenomena or R&D in particular areas with a view to their practical application (41 programmes in Russia, 21 in Belarus and 26 in Kyrgyzstan, for example). Funding for priority S&T programmes is usually distributed on a competitive basis and is allocated directly to R&D-performing units by national S&T agencies without passing through the academies' administration or branch departments.

A classification of priority S&T programmes by broad objective is given in Table 7. The CIS countries are trying to find new scientific and technological solutions for energy and food problems, while capital-intensive policies on energy production and consumption, as well as on agriculture, have almost exhausted opportunities for the future. An area of common interest is that of information technologies and telecommunications, seen as a necessary element of any market infrastructure. The more industrially developed countries (Russia, Ukraine, Belarus and Kazakhstan) have launched specific programmes aimed at the creation and application of new industrial technologies, whereas those rich in mineral and fuel resources are more interested in effective technologies for mining and new materials production (Azerbaijan, Kyrgyzstan and Turkmenistan). Special attention is being paid to environment protection issues, especially in the case of countries affected by the Chernobyl disaster (Belarus, Russia and Ukraine), the consequences of nuclear weapons tests (Kazakhstan) and the ecological problems of the Aral (Kazakhstan) and the Caspian (Azerbaijan, Kazakhstan and Turkmenistan) Seas. In Russia, an important part of its priority programmes is related to basic research in high-energy and nuclear physics, high-temperature superconductivity, space exploration, genetics, biochemistry, chemical substances, Arctic and Antarctic exploration, etc.

TABLE 7
OBJECTIVES OF PRIORITY S&T PROGRAMMES IN THE CIS COUNTRIES

	Armenia	Azerbaijan	Belarus	Kazakhstan	Kyrgyzstan	Moldova	Russia	Turkmenistan	Ukraine
Objectives									
Health			✓		✓	✓	✓	✓	✓
Ecology		✓	✓	✓		✓	✓	✓	✓
High technologies		✓	✓			✓	✓		✓
New materials		✓	✓		✓	✓	✓	✓	✓
Energy	✓	✓	✓	✓		✓	✓	✓	✓
Agriculture			✓	✓	✓	✓	✓	✓	✓
Mining	✓	✓		✓	✓		✓	✓	✓
Manufacturing	✓	✓	✓	✓			✓		
Construction			✓	✓		✓	✓	✓	
Informatics and telecommunications			✓	✓		✓	✓	✓	✓
Social problems	✓	✓	✓		✓		✓		✓

Source: Compiled by the author on the basis of information supplied by national authorities.

Reforms of S&T systems in the CIS countries have included the establishment of foundations aimed at supporting basic research in Belarus, Russia and Ukraine. These operate as self-governing institutions in open competition for grants to finance basic research performed not only by research institutes or universities, but also by small teams of researchers and individual scientists; the development of the material and equipment bases of R&D institutions; the acquisition of scientific literature; the granting of fellowships, and so on. Such funds are important for the support of research in specific fields (like pure mathematics, botany and zoology), which, being outside governmental programmes, are not provided with funding within the framework of R&D budget priorities. The Foundation for Fundamental Research was first established in Russia, to be joined by the Foundation for Humanities Research in 1994. The role of these funds remains limited, however, since their share does not exceed 3-4% of the civil R&D budget.

Another type of newly established foundation is represented by those aimed at supporting industrial R&D and innovation. They can be budgetary (for example, the State Innovation Fund in Ukraine and the Russian Fund for Promotion of Small Enterprises in S&T) or non-budgetary. In order to ensure funding for sectoral or intersectoral R&D and innovation, a network of non-budget funds was established in Russia in 1992 under ministries, agencies, associations and corporations. The resources of the branch funds are derived from levies paid by enterprises (1.5% of production costs). Twenty-five per cent of the total funds are accumulated in the centralized Russian Fund for Technological Development, to support R&D considered particularly essential for state and industry groups.

Non-budgetary funds for R&D have been established in Kazakhstan (the Kazakh Science Foundation) and Moldova (the Republican Fund for R&D Financing under the Ministry of Economy). These provide finance for both basic and applied research and are derived from budgetary sources and contributions from ministries, enterprises and abroad. Shareholding by interested ministries or enterprises in expenditure on applied R&D has become a necessary condition of budget financing of such projects in Belarus. In Kyrgyzstan even some government S&T programmes are financed on a loan basis.

THE INSTITUTIONAL STRUCTURE OF R&D

The institutional structure of the R&D base has experienced significant changes since the beginning of *perestroika* in 1985. R&D institutions became free to set their own research objectives and to spend their own funds. The contractual form of R&D support was introduced, and research institutes and enterprises became effectively self-financed.

In the market environment they have had to adjust to budgetary constraints and decreasing industrial demand. In order to preserve the large research institutes which are leaders in Russian science and internationally famous for their achievements in basic research and high technologies, a Programme of Support to the Federal Research Centres was adopted in Russia in 1993. By the end of 1994, 60 institutions had been accorded the status of recognized research institute, and it was expected that their number would increase to 70-75 by the end of 1995. Among these were the Kurchatov Institute of Atomic Energy, the State Optical Institute, the Research Centre for Shipbuilding and other institutes in nuclear physics, aviation and space, chemistry, biotechnology, electronics and instruments making. The federal research centres will coordinate the most valuable strategic long-term national priorities. Envisaged support measures for them include priority budget financing of R&D and experimental plants, reduced-rate tariffs for communal services and communications, tax concessions and accelerated depreciation.

In Kazakhstan, the government has organized national scientific centres in the areas of nuclear research (based on the Physics Institute of the Academy of Sciences), biotechnology, comprehensive mineral processing, pario-electronics and telecommunications, computer engineering and informatics and ecology to meet the needs of major state programmes. The State Centre for New Space Technologies is based on the Baikonur space-vehicle launching complex. In addition, scientific analytical centres were established by the Ministry of Science and New Technologies to design national programmes on the development of the rare metals industry, ecological monitoring, Caspian Sea studies, etc. National S&T centres have been organized in Kyrgyzstan with the aim of introducing high technologies into particular branches of industry.

Another important aspect of the transformation of R&D institutions concerns their privatization. In Russia almost 20% of industrial R&D institutes and design bureaux have been privatized, including some 100 large research units of the defence industry. Hundreds of industrial R&D units are now incorporated into industrial groups, associations and companies. Along with 34 800 small enterprises and 305 foreign-related joint ventures (1993), they represent an expanding non-government sector of R&D. A number of university-based technoparks have also been established.

Special attention is being given to a legal framework for S&T. In most, if not all the CIS countries, laws on national S&T policies have already been approved or are presently under parliamentary scrutiny. These define the principles of S&T policy elaboration and implementation, the administrative bodies involved and the financing procedures. A series of laws to provide for regulations on intellectual property have been adopted, including in the case of Russia the Patent Law, the Law on Trademarks, the Law on Legal Protection of Software and Databases, the Law on Legal Protection of Integrated Circuit Topology (all in 1992) and the Copyright Law (1993). However, more attention needs to be given to a legislative basis for entrepreneurship in S&T, a logical system of tax, trade and other incentives for R&D-performing institutions and universities.

Goals for S&T policy in turn are determining the objectives of a revision of R&D statistics (see box). Action undertaken in Russia to implement international standards in national R&D and innovation statistics (Gokhberg, 1993) is supporting policy making with a realistic picture of trends in S&T and provides the international community with increasingly transparent information.

INTERNATIONAL S&T COOPERATION

Disintegration of the USSR has obliged the newly independent states to develop their own strategies in international S&T cooperation, something that was, once again, previously organized centrally. Direct linkages between research institutes and enterprises of the former Soviet republics had been integral elements of a common economy. Now they have become a means of S&T collaboration within the CIS as a new specific dimension of regional S&T cooperation.

An agreement on S&T cooperation between member countries of the CIS was signed by the heads of governments in March 1992 in Moscow. The motives underlying such collaboration were related to a long-term interest in preserving national R&D bases and providing for their improvement through both multilateral and bilateral initiatives. This is particularly important in the case of large-scale research projects, e.g. of basic research; unique scientific facilities and experimental plants of overall importance that are excessively expensive for an individual country to maintain; the training of scientists and engineers; S&T information and the protection of intellectual property. It was agreed that there should be areas identified for interstate programmes of basic research, projects on development and the implementation of new technologies, scientific and technological facilities

S&T statistics in the CIS countries

S&T statistics in the USSR were developed under the influence of the centralized S&T planning and funding system and their official role was limited to the informational support of governmental bodies. These S&T statistics were based on gross indicators and were ill suited to analytical study. Soviet R&D statistical data were as a rule incompatible with international standards because of differences in the objects of surveying, methods of accounting, data collection and processing.

As a product of rigid centralization, the USSR Central Statistical Agency alone was in charge of methodology of R&D statistics, data aggregation and publications. Thus all the related expertise was concentrated in Russia, while the other republics had neither experience nor tradition in the subject.

In December 1993 the Ministry of Science and Technology Policy (MSTP) and the State Committee on Statistics of Russia issued a joint statement aimed at the improvement of R&D and innovation statistics. According to the statement, the Centre for Science Research and Statistics (CSRS) established in early 1991 and subordinated both to MSTP and the Russian Academy of Sciences, was to be directly responsible for S&T statistics methodology, the implementation of the international statistical standards, data analysis and software for data processing. The CSRS was also authorized to represent the Ministry in relations with interested international organizations in the field of S&T statistics.

In line with S&T policy objectives the CSRS has designed new national R&D and innovation surveys in line with OECD standards and the experience of the European Union. The priority areas to be developed further include governmental budget R&D funding, human resources in S&T, technological balance of payments, patent and regional statistics. The Centre also has an ambitious programme of statistical publications. The CSRS methodological developments have attracted the interest of the CIS Statistical Committee and individual countries, and their results are being considered for dissemination in other former Soviet Union states.

for joint use; and the mutual recognition of scientific degrees. An Interstate S&T Council with headquarters in Kiev was established to coordinate cooperation in S&T between member countries.

The International Association of Academies of Sciences was founded in Kiev in September 1993, with the participation of the CIS countries plus the Czech Republic, Slovakia and Viet Nam. It was declared an association open to other states to collaborate in basic research, support prospective research projects and coordinate academy policies.

While S&T cooperation between the CIS countries has been supported by both multilateral and bilateral intergovernmental agreements it is still not carried out on the widest possible scale. Unstable political and economic relations between the CIS countries, domestic financial problems in research units and industrial enterprises, and even difficulties of fund transfers, all serve to hamper the re-establishment of contact at the level of the R&D practitioner.

Due to differences in R&D potential and opportunities for S&T cooperation the CIS countries participate in major multilateral international collaborative efforts to a varied extent.

Russia enjoys the most developed international S&T cooperation, thanks to its participation in collaborative activities undertaken by UNESCO, the United Nations Industrial Development Organization (UNIDO), the United Nations Environment Programme (UNEP), the World Health Organization (WHO), the International Council of Scientific Unions (ICSU) and many other international and regional S&T organizations and programmes. Cooperation with the European Union is increasing; common interests include public health and medicine, new materials, telecommunications, information systems, new sources of energy, biotechnology, agriculture and food production. In 1993 the government of the Russian Federation approved a decision to join the EUREKA Programme. Russian scientists also collaborate in the large multilateral programmes on high-energy physics, nuclear energy and safety (the European Organization for Nuclear Research – CERN, the International Thermonuclear Experimental Reactor – ITER and the International Atomic Energy Agency – IAEA) and on space exploration. Since 1992 scientific cooperation has been organized between Russia and NATO.

Among recent large-scale international initiatives aimed at supporting S&T in the CIS there are the Technical Assistance for the Commonwealth of Independent States (TACIS) Programme of the European Union (from 1991) and the International Association for the Promotion of Cooperation with Scientists from the Independent States of the Former Soviet Union (INTAS), established in Brussels in 1993. In its first four years of operation, 1991-94, TACIS has made 1 900 million ECU (US$2 500 million) available to launch more than 2 000 projects, providing Western know-how combined with local experience (European Commission, 1994: 308, 309). INTAS plays an important role in supporting the twinning of research teams and individual scientists from the West and newly independent states in all fields of natural sciences, engineering, humanities and social sciences. The total funding for 1994 is 21 million ECU (US$27.5 million) (*op. cit.*: 308).

The International Centre for Science and Technology (ICST) was opened in Moscow in 1994 in accordance with an agreement signed in November 1992 by the representatives of the European Union, Russia, the USA and Japan. Subsequently, Finland, Sweden and Georgia became members, and Canada, Belarus, Armenia and Kazakhstan have expressed their intention to join. ICST activity is oriented towards facilitating the conversion of military and nuclear research to civil purposes, and supporting basic and applied research projects in the fields of nuclear security, environment protection, chemistry and laser technology. It is expected that 4 000-5 000 scientists could be involved, and the funding commitment is US$80-100 million (*op. cit.*: 311).

The USSR conducted bilateral S&T cooperation with foreign countries over a period of more than 25 years. In Russia the legal framework for collaboration in S&T takes the form of some 100 intergovernmental agreements with most industrialized and developing countries, and 52 intergovernmental and more than 400 interdepartmental agreements with countries in Eastern Europe and South-East Asia previously belonging to the CMEA. In 1992-94 the government of the Russian Federation revised agreements concluded by the former Soviet Union, and new agreements have been signed with China, the Republic of Korea, India and the Republic of South Africa, as well as a protocol agreement with Chinese Taipei.

The Russian and Ukrainian academies of sciences have concluded a number of agreements with the national academies and research centres of the USA, Germany, France, Italy, the UK, Israel, and so on.

In Kazakhstan it is planned to launch joint studies on ecological monitoring from space in cooperation with NASA and the French National Space Agency. Other important areas of bilateral collaboration cover mining, renewable energy sources, satellite communications, pharmaceuticals and training in advanced technologies.

The CIS countries are also developing regional bilateral S&T cooperation with neighbouring states: examples include Moldova with Romania; and Azerbaijan and countries of Middle Asia with Turkey, Iran and Afghanistan.

Effective cooperation is being achieved through the establishment of international research centres, such as the Baikal International Centre for Ecological Research, the Euler International Mathematics Institute in St Petersburg and the International Physics Institute in Moscow, as well as joint universities (e.g. the Russian-American University and the Russian-French University of Informatics and Applied Mathematics).

Direct contact between counterpart institutes, companies and individual researchers is also an essential part of international S&T cooperation, and this is increasing in influence as the political and economic situation stabilizes and the legislative base improves. At present Russian research institutes and enterprises are carrying out more than 200 projects with foreign partners, and the exchange of researchers is also on the rise.

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The Arab States

SUBHI QASEM

The Arab States comprise a highly diverse group of countries that vary widely in size, wealth, state of science and technology and level of social and economic development. Some states, like Somalia, Sudan and Mauritania, are classified amongst the poorest in the world, with gross national product (GNP) per capita income of US$400-600 for 1992, while others like the oil-exporting Gulf States are among the richer countries with US$17 000-20 000 GNP per capita income. In spite of the increase in overall Arab GNP in the early 1990s from its levels of the mid-1980s, the Arab States have become poorer with time. The average GNP per capita income for all states for 1992, for example, was about US$2 000 compared with almost US$2 600 in 1980.

The overall development of science and technology (S&T) in the Arab States has not, on the whole, been satisfactory in recent years. Development in higher education, albeit with some weaknesses in output, has been much more positive than in research and development (R&D) activities. The general picture, whether positive or negative, does conceal wide disparities among the countries of the region. One cannot speak of any aspect of the Arab States without considering the political, economic and security problems that have confronted many of them. Somalia, for example, has been devastated by a decade-long civil war, while Lebanon, long recognized for its strengths in a number of areas, especially in higher education, is now emerging from another civil war which lasted for more than a decade. Other Arab countries are suffering from a wide range of difficulties that include international boycott, as in the case of Iraq and the Libyan Arab Jamahirya, or civil disturbances, as in Algeria, Sudan and Egypt, and these problems, coupled with decreasing oil prices on the world market for the last decade, have left their mark on most, if not all Arab States. On the other hand, the Arab-Israeli peace process, which started in 1992, may eventually replace the Arab-Israeli war that has flared off and on over the last 50 years. Although the impact of the much hoped for peace may be profound, few tangible positive developments have taken place thus far.

HIGHER EDUCATION IN SCIENCE AND TECHNOLOGY

Overview

Institutional capacity in higher education in the Arab States has developed rapidly over the last 14 years. About 50% of the 132 universities that were operational in 1993 were actually established between 1980 and 1993. In 1992 about 2.4 million Arab students attended higher education institutions, of which only 4.6% were enrolled in institutions outside the Arab States. Those studying within the region were enrolled in 132 universities, 136 university-level colleges or institutes operating independently of the universities and 437 two- to three-year community colleges or technical institutes granting diplomas. The distribution of student enrolment by level of study has varied widely among the Arab States but has averaged 15.7% of the total for the diploma level, 78.6% for the first-degree or Bachelor level, 4.3% for the Masters and only 1.4% for PhD level. The ratio of students enrolling in S&T fields in each level has also varied between countries but averages as percentages of the total enrolment are 45% for the diploma level, 34% for BSc, 49% for MSc and 67% for PhD. These ratios were not significantly different from those in 1984/85, except for the diploma and Masters levels (see Table 1).

Trends in S&T education

The rate of growth of S&T enrolment at the first-degree or Bachelor level averaged 4% per year over the period 1980-92, compared with 9% for the humanities and social sciences and 7% for the total. The distribution of S&T students by field of study has changed over the period 1980-92 (see Figure 1). Although the absolute numbers in each field have increased in all fields, the percentage of engineering students, for example, fell to 10% in 1991/92, compared with 14% in 1979/80. The percentage of students enrolled in the basic sciences, on the other hand, has increased to 12% in 1991/92 compared with 9% in 1979/80.

TABLE 1
STUDENTS ENROLLED IN TERTIARY EDUCATION IN THE ARAB STATES, WITH RATIO OF S&T TO TOTAL ENROLMENT, 1984/85 AND 1991/92

	1984/85		1991/92	
Level	Number ('000s)	% S&T	Number ('000s)	% S&T
Diploma	282	37	372	45
Bachelor	1 484	36	1 861	34
Masters	55	57	103	49
PhD	23	64	32	67
Total	1 844	-	2 368	-

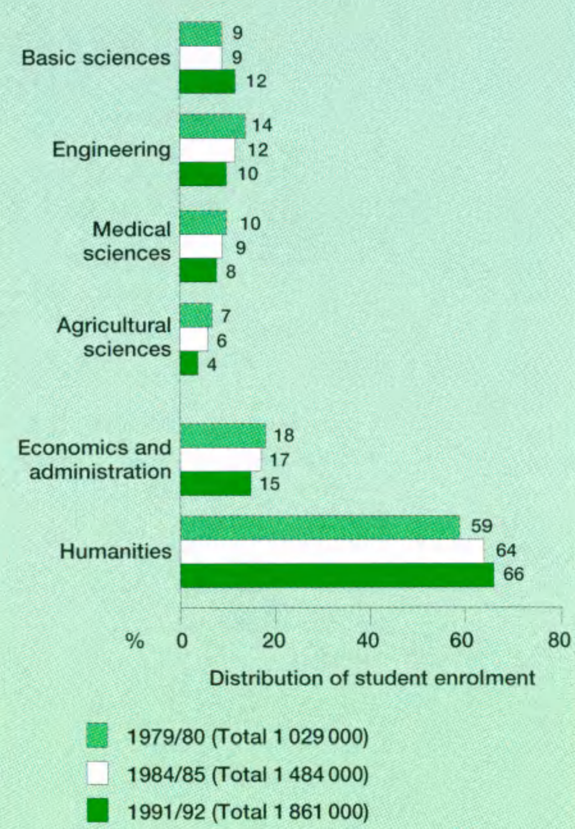
Source: Qasem, 1990; Qasem, 1995*a*.

The capacity of Arab higher education institutions has not developed at the Masters and PhD levels as it has at the first-degree level. Arab institutions were able to accommodate almost 95% of students enrolled at the Bachelor level, with only 5% studying outside the Arab region. On the other hand, only 55% and 35% of those enrolled at the Masters and PhD levels respectively were enrolled in their home country institutions. The rate of annual growth in graduate studies averaged 12% between 1980 and 1992, compared with 7% for the Bachelor degree in all fields. However, the rate of growth in S&T fields at the graduate level was 10% compared with 4% at the BSc level. The ratio of graduate students to total university level enrolment has remained among the lowest in the world, though reaching 6.5% in 1992 compared with 4.8% in 1980.

The share of S&T of students enrolled at the MSc and PhD levels has decreased over the years, reaching 51% in 1992 compared with 60% in 1980. The distribution of student enrolment by S&T field has not changed significantly over the last 14 years, with medical sciences maintaining their top position throughout the period, followed by basic sciences (see Figure 2).

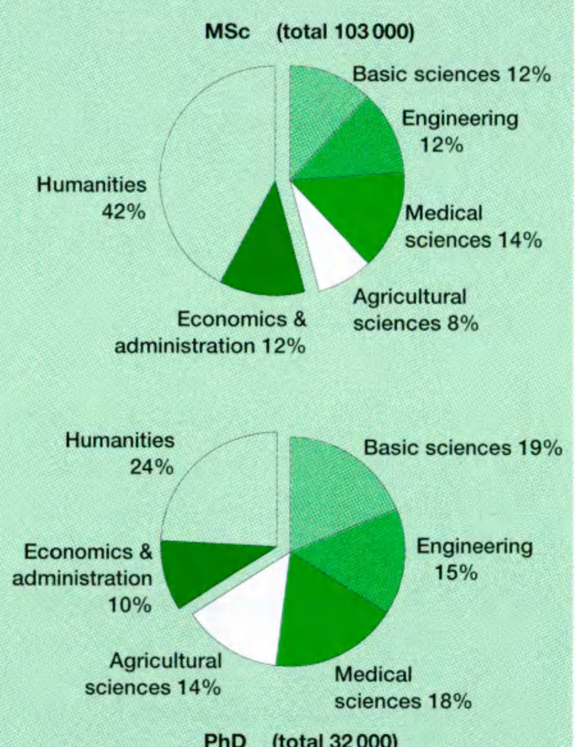
The ratio of females in higher education has improved over the years, reaching 35% in 1991/92, compared with 29% of total first-degree enrolment in 1979/80. Female students dominated the enrolment in the humanities and the social sciences, with an average of 69% for all Arab States. The S&T field in

FIGURE 1
DISTRIBUTION OF FIRST-DEGREE STUDENT ENROLMENT IN THE ARAB STATES BY FIELD OF STUDY, 1980-92



Source: Qasem, 1990; Qasem, 1995*a*.

FIGURE 2
DISTRIBUTION OF MSc AND PhD STUDENT ENROLMENT IN THE ARAB STATES BY FIELD OF STUDY, 1992



Source: Qasem, 1995a.

which females had the highest enrolment (of total female student enrolment) was basic sciences, with 12%, followed by medical sciences with 9%, engineering with 8% and agriculture with 3%.

Average student enrolment at first-degree level in all fields and for all Arab States was 815 per 100 000 inhabitants in 1992, with national levels showing wide variation, from the 96 per 100 000 inhabitants of Somalia to the 2 198 of Lebanon (see Figure 3).

The ratio of students enrolled in S&T fields, on the other hand, differed from that of all-fields enrolment at the first-degree level. The overall average was 275 but varied widely among Arab States (see Table 2).

Human S&T capital formation

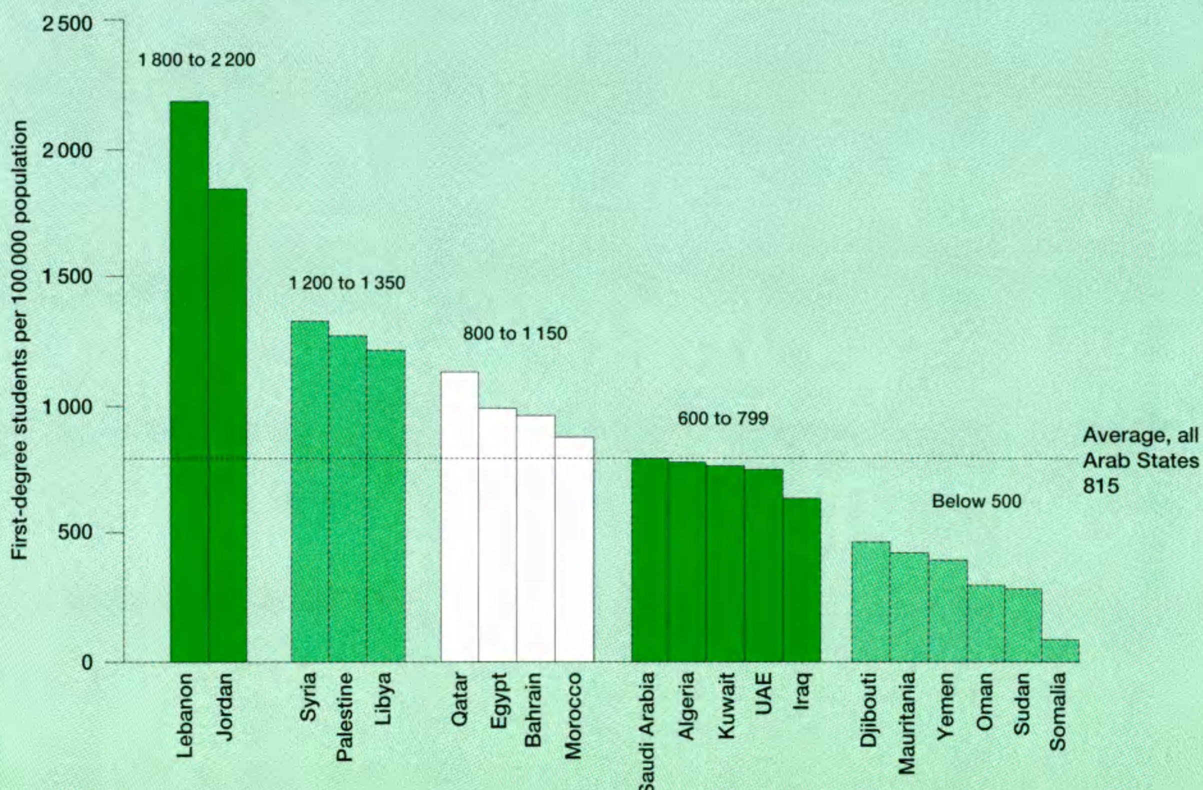
Human capital formation has remained the primary function of higher education institutions. In 1992, about 95% of university budgets was devoted to human resource development, leaving only 5% for research and other functions. The human capital output of university-level institutions has been dominated by first-degree graduates. In 1990/91 university graduates numbered 291 700, of which 94.2% were at the Bachelor level, 4.3% at the Masters and 1.5% at the PhD level. The share of S&T graduates was 35% of the total, of which 12% were in natural sciences, 10% in engineering, 8% in medical sciences and 5% in agriculture and veterinary sciences.

The pattern of cumulative human capital formation in S&T during the period 1980/93 did not differ much from that of 1990/91. Bachelor's degree holders made up 95.2% of all graduates, leaving 3.6% to Masters and 1.2% to PhD holders. The total number of first-degree graduates for the 14-year period 1980-93 amounted to about 3.2 million, compared with 121 000 Masters graduates and 39 000 PhD holders. The share of Masters and PhD holders who graduated outside the Arab region during the 14-year period was much higher than first-degree graduates and came to 21% for Masters and 52% for PhDs compared with only 5% for Bachelors of total graduates at each level. The distribution of Masters and PhD graduates by discipline was considerably different from that of first-degree graduates (see Figure 4).

These averages embody a wide variation among Arab States with regard to the ratio of the various levels of graduate, the S&T ratio and the per capita share of total graduates. The average number of university graduates per 100 000 population in 1993 amounted to about 1 420 for all Arab countries, of which 8 were higher than average and constituted 30% of total population, while 13 states were below the average and constituted the remaining 70%. The variation among the states ranged from a high of 3 070 per 100 000 of the population to a low of 300.

FIGURE 3

CATEGORIES OF ARAB STATES IN DISTRIBUTION OF FIRST-DEGREE STUDENT ENROLMENT ALL SUBJECTS, PER 100 000 POPULATION, 1992



Source: Qasem, 1995a.

In conclusion, it can be said that the Arab higher education system has been successful in the formation of human capital at the first-degree level but less so at producing much needed graduates at the Masters and PhD levels. Most Arab States suffer from unemployment among first-degree graduates, even in some S&T fields, but at the same time there is a demand for Masters and PhD graduates and especially the latter. The fact that 37% of university teaching staff and 51% of research staff of institutions performing R&D activities outside the universities are only MSc holders shows the potential need for PhD holders. This situation underlines the urgency of a shift to a more balanced output of human capital formation in which graduates at MSc and PhD level would be increased to 10% within the next 10 years and later would approach the ratios prevailing in most developed countries, which in 1990/91 came to 1 PhD and MSc to every 4 first-degree graduates, compared to 1 to 19 for the Arab States. For this shift to take place, Arab States must invest sizeable funds in strengthening graduate study programmes.

Future outlook for Arab higher education

Most Arab States adopted an open-door admissions policy towards higher education. This came at a time when both high school graduates and numbers in the university age group were increasing at unprecedented rates. The numbers in the university age group, which

TABLE 2

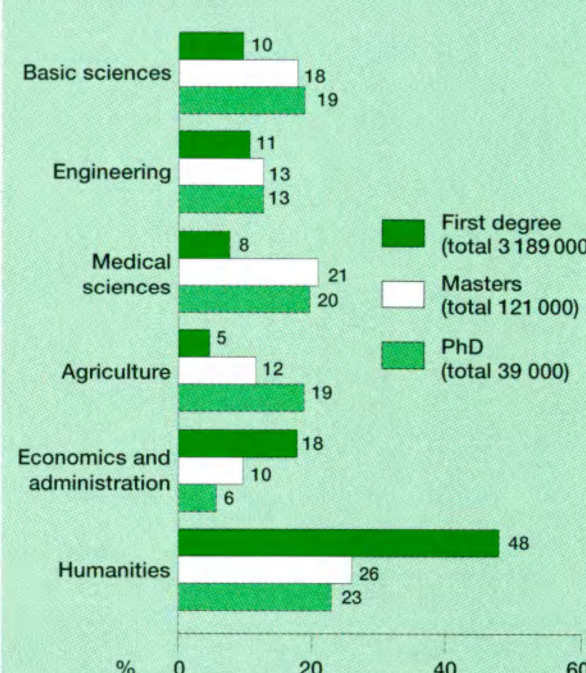
NUMBER OF FIRST-DEGREE STUDENTS ENROLLED IN S&T FIELDS PER 100 000 INHABITANTS DISTRIBUTED BY ARAB STATE, 1992

S&T students enrolled on first-degree courses per 100 000 inhabitants	Country
865	Jordan
530-630	Lebanon, Syrian Arab Republic, Algeria
380-480	Palestine, Libyan Arab Jamahiriya, Bahrain, Morocco
275	**Average, all Arab States**
230-320	Qatar, Kuwait, Tunisia, Egypt, Iraq, Saudi Arabia
100-200	UAE, Mauritania, Oman, Djibouti
Below 100	Yemen, Sudan, Somalia

Source: Qasem, 1995a.

FIGURE 4

PERCENTAGE DISTRIBUTION OF FIRST-DEGREE, MASTERS AND PhD GRADUATES BY DISCIPLINE IN THE ARAB STATES, 1980-93



Source: Qasem, 1995a.

averaged close to 10% of the population in the Arab States in the 1980s, are expected to remain high in the 1990s at around 9%.

The Arab States, with the exception of Egypt, have responded to the increasing demand for university education by expanding admission rates. The number of students admitted to public universities in Morocco, for example, has doubled within the four-year period 1989/90 to 1993/94. In Sudan, the number of students admitted to government institutions jumped to 25 100 in 1993/94, compared with 5 100 in 1989/90, a five-fold increase in just four years. Numbers of students admitted to public universities in Jordan have increased by 25% since 1988/89.

The overall response to this increasing demand for higher education may be summarized as follows:

- Many countries have promoted the establishment of universities and colleges financed through the private sector. The number of these institutions reached 122 by 1994.
- Several countries have established open university systems to accommodate the maximum number of students in their resident areas.
- All Arab countries have promoted admission to two- and three-year community colleges and technical schools.
- Most Arab countries have expanded the number of

universities, especially in regions away from their capitals.

According to the indicators, this expansion in admission has unfortunately lowered the quality of higher education in many Arab States. Higher education expenditure in 1992, for example, rose to an all-time high of US$396 000 million, equivalent to 0.81% of GDP. The share of each student of the total university budget, on the other hand, decreased to US$1 891 in 1992 compared with US$2 062 in 1985 at current prices. Staff time allocated to research also went down from a full-time equivalent of 10% of total staff in 1984/85 to 6% in 1992.

Forecasts for the coming few years suggest the following developments in higher education systems in the Arab States:

- The percentage of students enrolled in S&T fields will continue to decrease, perhaps at higher rates than at present.
- More and more resources, both in terms of staff time and funds, are likely to be allocated to BSc programmes, a situation that may not allow substantive improvement in the prevailing low ratios of graduate students to total student enrolment.
- Research activity in the universities, a most important function, will continue to suffer from the low level of funding.

RESEARCH AND DEVELOPMENT

Organization

Scientific research in the Arab States is carried out in universities as well as in R&D institutions organized outside the universities. Each department in an S&T college, whose numbers reached 557 in 1993, is a potential research unit. However, the time allocated to research by university staff members has, on the whole, been decreasing over the last 10 years due to the increasing teaching load. Research in departments that offer graduate studies has also suffered, due to limited admission rates (with the exception of those in Egyptian universities). Out of a total of 1 417 departments in basic sciences, engineering and agriculture, only 30% offered PhD programmes compared with 54% that offered the MSc. In 1990/91, the total output of university graduate programmes in all S&T fields was 4 100 MSc and 700 PhD graduates respectively. If each graduate were to write a thesis, the number of research publications would still be very modest for a group of states having 224 million inhabitants. The number of full-time equivalent research staff was also small and was calculated to reach only 4 700 across all fields of research, a number equivalent to a mere 6% of total university staff members.

Many universities have established S&T research centres to better organize, finance and monitor research activities in priority areas. Out of a total of 42 such centres, 30% were in agriculture and its related fields, 26% in health, 14% in engineering and 30% in all other fields including petroleum, basic sciences, environment and biotechnology.

R&D activities outside the Arab universities, on the other hand, are organized on a variety of institutional models. Out of 244 R&D structures, there are 5 corporations, 94 centres, 61 institutes, 75 divisions and 9 programmes. The name corporation is used in only a few countries. R&D is organized in Sudan, for example, in several commodity centres. The centre is the most commonly used organizational structure. Centres may be built around monodisciplinary (commodity) or multidisciplinary R&D activities. Divisions are usually organizational structures of centres, institutes or simply research units standing on their own within a ministry. They usually enjoy the lowest degree of autonomy among all R&D institutions except for programmes.

R&D distribution by area of research

R&D institutions in food and agriculture are the most developed in the Arab States. In 1993, a total of 105 institutions were operational in agricultural production systems, water and irrigation, marine science and fisheries, forestry, food technology, desert studies and environment. The other R&D institutions may be divided among seven major areas of research (Table 3).

Research staff in the Arab States totalled 14 500 in 1992, of which 53% were PhD and 47% MSc holders. Support staff at the BSc level came to 6 800, while technicians and administrative staff totalled 28 500. This means that support staff are in greater supply and are in the ratio of 2.4 to each researcher. The overall number of research staff in the Arab States is among the lowest in the world: the ratio of researchers in 1992 came to one researcher to every 4 295 of the work force, or one researcher to every 15 000 of the population. About one-third (32.5%) of research staff work in the universities, while the other two-thirds are distributed amongst R&D institutions outside. R&D activities continue to be public sector concerns, with less than 1% being implemented by the private sector in all areas.

The allocation of research staff to various areas of research varied widely in 1992. The highest share, 44% of total research staff, was allocated to R&D activities in agriculture and allied areas, including water and irrigation, fisheries, food technology and forestry. The balance of 56% was allocated to all other areas of research, made up of health, energy, petroleum, basic sciences, minerals, remote sensing, industry, education, humanities and the social sciences (Table 4).

The averages presented in Table 4 conceal large disparities among the Arab States. The share of Egypt, for example, comes to 52% of the total research staff, while it has just 24% of the total population of the Arab States. Another country of good standing is Morocco, with 9% of total Arab research staff and 11% of the total Arab States' population. All other Arab countries combined had a share of 37% of total research staff, but with 65% of the total population.

R&D expenditure

In the great majority of Arab States, R&D has remained a public sector activity in which governments are the

TABLE 3
R&D INSTITUTIONS IN MINISTRIES (OUTSIDE UNIVERSITIES) AND THEIR DISTRIBUTION BY AREA OF RESEARCH IN THE ARAB STATES, 1992

Area of research	Corporation	Centre	Institute	Division	Programme	Total
Agriculture, fisheries, forestry, water and food technology	3	36	31	33	2	105
Health, nutrition and biotechnology	–	12	9	8	2	31
Energy	1	14	5	7	1	28
Industry	–	5	6	11	2	24
Geology, remote sensing, meteorology and basic sciences	1	10	1	7	1	20
Engineering	–	3	4	5	–	12
Petroleum and petrochemical	–	3	4	2	–	9
R&D planning and coordination	–	4	1	2	1	8
Education development	–	7	–	–	–	7
Total	5	94	61	75	9	244

Source: Qasem, 1995*b*.

sole domestic source of funding. The level of R&D expenditure has fluctuated over the years, but a decreasing trend has been evident since the mid-1980s, when a large number of Arab States started to face economic difficulties. The situation worsened as a result of the Gulf War, when sizable funds were cut from national budgets and diverted to military activities. Unfortunately, funds formerly allocated to research were the hardest hit. It often happens that funds allocated to research are encouragingly high initially but that expenditure is very susceptible to reduction when government budget cuts take place.

In 1992, the total R&D expenditure from domestic sources in all Arab States came only to US$548 million, of which 99% was from public funds and only 1% from the private sector. This figure is much lower than the levels prevailing in the mid-1980s, a period in which R&D expenditure peaked in several states. Most non-oil exporting Arab States have received research support funds from bilateral, regional and international agencies under technical assistance programmes. This outside support has fluctuated over the years, peaking in the early and mid-1980s but decreasing in the late 1980s and the early 1990s. Among the major recipients of such outside support were Egypt, Morocco, Tunisia, Jordan, Sudan and Yemen. The level of this support reached an average of US$90 million per year during the mid-1980s but decreased to a mere one-third of this amount in the early 1990s.

The level of R&D expenditure is on the whole much lower than the threshold point required to carry out meaningful research. The average ratio of R&D expenditure to GDP in the Arab States amounted to only 0.1%. This figure, however, covers wide disparities in levels of national expenditure among the states. In turn, state expenditure averages also conceal wide variations amongst levels of support to the various sectors; the share of agricultural R&D, for example, constitutes just over 40% of total expenditure. In some countries, it approaches the minimum threshold level – considered by international standards to be 1% of sectoral GDP. Agricultural output contributed 14% of total Arab GDP in 1992, but consumed 42% of total expenditure

TABLE 4
RESEARCH STAFF (PhD AND MSc HOLDERS) AND THEIR DISTRIBUTION BY AREA OF RESEARCH IN THE ARAB STATES, 1992

	Research staff			
Area of research	Total	% of PhD	Share of universities of total (%)	BSc support staff
Agriculture and allied fields	6 400	53.1	10.5	3 200
Health, nutrition and biotechnology	2 100	53.7	57.6	800
Geology, remote sensing and engineering	2 100	59.0	63.1	1 100
Humanities and social sciences	1 500	62.2	85.7	400
Energy	1 500	42.0	2.7	900
Industry	900	43.0	5.6	400
Total	14 500	53.0	32.5	6 800

Source: Qasem, 1995*b*.

on research. On the other hand, the share of oil and gas production to total GDP amounted to 21%, while their share of total R&D expenditure came only to a little less than 5%. Manufacturing is another sector in which the share of GDP, at 10% in 1992, far exceeded the share of R&D expenditure, which totalled only 4%. Health and nutrition research came second to agriculture in size of funds and consumed close to 15% of total expenditure.

Financing of R&D activities follows the general pattern applied to other public institutions. The salaries of researchers and research support staff constitute the largest item in the budget, with marginal allocations going to operational funding. Programmes of research are on the whole identified with little input from the targeted clients. Traditionally, therefore, research activities have been supply-driven. In several Arab countries research planning, coordination and finance institutions have been established in recent years. The Egyptian Academy of Science and Technology, the Kuwaiti Foundation for the Advancement of Science, the Jordanian Higher Council for Science and Technology and the Saudi King Abdulaziz City for Science and Technology are examples of such institutions, whose objective is to bridge the gap between supply-driven and demand-driven research. Each institution allocates funds to support research identified and coordinated by producers as well as by users. The research support budget of these institutions, however, does not exceed 5% of total R&D expenditure in their respective country, and their impact in reorienting research to national needs and demands therefore remains far below expectation.

The future outlook for R&D activities does not look good. With the exception of Egypt, which has a good supply of PhD and MSc personnel, most countries in the region are short of scientists sufficiently qualified to carry out research. Over 50 universities have been established during the last 10 years. Many more are being planned and will become operational during the coming few years. Such universities compete for available PhD and MSc holders. Existing universities in most Arab countries employ large numbers of MSc holders hired to carry out functions usually assigned to PhD holders. As was mentioned earlier, Masters holders already make up 37% of total teaching staff in Arab universities. If Egypt is excluded, the representation of Masters holders on the total teaching staff of all Arab universities rises to 44%. In 1992 the share of universities in total research expenditure was 34%, a figure much lower than levels existing in the mid-1980s. The demand on staff time for teaching is likely to rise in the coming years, a situation that may marginalize university research efforts in most countries. Egypt is the only Arab country that may not suffer from the decreasing role of universities in the national research effort.

Funds allocated to R&D activities are not expected to rise sharply in the coming years. What is possible, however, is that some states may opt to concentrate their R&D activities in one or two areas and therefore have a better chance of providing sufficient funds for their effective implementation.

The role of industry and other private sector parties in support of research is promising in several Arab States but is moving at a much slower rate than expected. Several countries have provided incentives for industries to establish their own R&D units. All Arab States have agreed to join the World Trade Organization that emerged out of GATT in 1994. If Arab exports are to be competitive in regional and international markets, and indeed in their own markets, the states must adopt more aggressive policies for the development of goods. This will certainly create a demand for R&D activities and such related technical services as quality control and standard operational procedures.

POLICIES FOR SCIENCE AND TECHNOLOGY

S&T policy-making bodies

Most, if not all, Arab States have established a national S&T policy-making body. Traditionally, the models of a ministry of higher education and a council of scientific research were adopted for policy-making bodies for higher education and research institutions respectively. In recent years several models have emerged for S&T policy-making bodies. These have included a higher education ministry, a scientific research ministry, an S&T council, a ministry of higher education and scientific research and a council for higher education. In addition, the S&T policy-making body may carry a different name but function like a ministry, as is the case with the King Abdulaziz City for Science and Technology of Saudi Arabia.

In most Arab States, policy-making bodies responsible for higher education are separate from those mandated to formulate R&D and technical service policies. Ministries for higher education and scientific research, such as those existing in Iraq, Yemen, Sudan and Algeria, are responsible for higher education institutions and research in universities but not for research in other ministries. In all Arab States, research institutions and universities are older than the new institutionalized S&T policy-making bodies. Many universities have enjoyed a large margin of autonomy, while R&D institutions were established either under autonomous boards or under the direct control of individual ministries. Until now, the vast majority of agricultural research, for example, has been planned, financed and implemented under the ministry of agricultural affairs in each Arab State. The same goes for health, industry and energy. Few R&D institutions enjoy great autonomy, and those that do are usually multidisciplinary. These historical developments in S&T institutions have made it difficult thus far to produce harmonious working relationships between S&T policy-making bodies and S&T implementing institutions.

Policy objectives and instruments

Although policy-making bodies operate under various names they do all share the feature of being formed at the highest executive level. They are often chaired by a minister or by a high-ranking official of ministerial standing. The establishment of such bodies came in response to what policy makers perceived as a need to plan, coordinate and consolidate S&T activities in each Arab State.

The objectives of higher education policies often include most, if not all, of the following:

- Provision of higher education opportunities for the largest number of those seeking them. The policy is closer to an open-door university admission than a rationed one. Only one country, Egypt, declared in 1984 a more systematic admissions policy, especially for S&T university colleges at the BSc level. By contrast, Egypt had been the first Arab State to adopt open-door admission to universities as far back as the late 1950s.
- Provision of higher education in fields of study consistent with national development objectives and societal needs.
- Provision of free-tuition higher education in which the government is responsible for all university costs. Exceptions to this policy may be found in only one state and in the Palestinian Occupied Territories.
- Provision of high-quality education and, in some cases, education of excellence.

Unfortunately, the means provided for achieving these objectives have proved to be far below the required level in all non-oil exporting states and even in some oil exporting ones. Most universities suffer from low levels of finance, and many of them have failed to provide quality education consistent with international indicators. Many of the universities have not been able to respond in time to the changes and demands of the social and economic sectors. Due to the progressive expansion in admission at the first-degree level, the universities have not had the means of developing their capacity beyond this level, consistent with increasing demand.

On the other hand, the objectives of R&D policy-making bodies included the following:

- Identification of R&D and technical services in prioritized plans consistent with the needs of the social and economic developmental sectors.
- Maximal use of resources allocated to R&D activities through the coordination and consolidation of activities of all R&D institutions.
- Promotion of linkages among all stakeholders in R&D and technical service activities, especially among users and producers.
- Creation of a healthy environment for high productivity of R&D and technical service staff.

The degree to which policy-making bodies have been successful in meeting R&D and technical service objectives has varied considerably among the Arab States. Experience shows that performance of these bodies depends largely on the type and effectiveness of the instruments employed to achieve policy objectives. Many countries, for example, have resorted to the formation of committees representing all stakeholders to plan and coordinate R&D resources and activities, but there is little evidence to suggest that such committees were effective in bringing about the desired changes. A more successful mechanism, however, proved to be the financial support tool that was exercised outside the normal budget of R&D institutions. Unfortunately, the size of this support to policy institutions was far below the level needed to have comprehensive impact. In several cases, financial support was not sustained at initial levels, and eventually lost its ability to produce the desired objectives. In 1988-92, the average annual support provided by policy-making bodies to R&D programmes in four Arab States – namely Egypt, Jordan, Kuwait and Saudi Arabia – amounted to 3.6% of total R&D expenditure.

Research contracted between users and producers of R&D is another successful mechanism for increasing the relevance of R&D output to the demands of users. Again this instrument, although effective and popular, has not gained momentum, due to the low levels of funding available on one hand and to the independent funding pattern of R&D institutions operating under various ministries on the other. The pattern of funding of R&D institutions governed by the ministries of agriculture, for example, provides salaries and operational funds for normal institutional activities. Normally, operational funds are hardly sufficient to produce quality and effective output. Institutions usually fight for more, but the traditional financial procedures of the ministries do not allow for providing adequate funds. As a result, researchers are usually content to carry on business as usual, there being little incentive to seek additional support, which usually comes with conditions and which thus remains unpopular for the majority of the research community. Most researchers are used to formulating their own research agenda, setting their own priorities and reporting their research results in the form of publications suitable for their own promotion; outside evaluation is usually resisted. The relationship between researchers and senior administrators has reached a form with which both seem to be comfortable. What is needed is policy interventions that will break this cosy relationship and produce a state of affairs that is more realistic in achieving policy objectives.

In conclusion, most Arab States have invested sizeable sums in building higher education as well as R&D institutions. The fact that many Arab States have established S&T policy-making bodies and have further formulated S&T policies was a necessary condition but not sufficient to ensure an effective S&T system. There is plenty of evidence to support the notion that a wide gap exists between declared S&T policy objectives in many Arab countries, and the instruments needed to achieve such objectives. The gap between declared objectives and implementation mechanisms is generally wider in R&D.

RESEARCH PRIORITIES, PAST PERFORMANCE AND FUTURE TRENDS

Overview

On the whole, the Arab States have been recipients rather than generators of R&D know-how in recent times. With the exception of certain achievements in agriculture and in natural resources development, the contribution of the Arab region to world R&D has been marginal as compared with the industrialized countries.

The Arab States are endowed with 61.8% of the world's oil reserves and 21% of its gas reserves. They also enjoy a geographical location that gives them the possibility of exploiting solar energy extensively. Their proven mineral reserves are vast, especially in phosphate and potash. On the other hand, the Arab States are poorly endowed with water resources. The desert and the arid climate that prevail over 82% of the Arab region have, together with scarce water resources, limited the amount of land suitable for stable food production. The per capita share of potential renewable water resources, of which 60% is already being used, has been decreasing over the years and has reached close to 1 100 cubic metres, a figure equivalent to only 12% of the world per capita average. By the year 2000, the per capita share of water that would be actually available for consumption will remain, based on the more promising scenarios of potential water resource development, at around 550 cubic metres, which is about the present level.

The total human capital in most Arab countries still suffers from structural weaknesses, with first-degree graduates dominating university output with a ratio of 19 Bachelors to one Masters and PhD. In a region that has one of the highest population growth rates, the increasing demand on food, health and educational services will continue to consume most, if not all, expected improvements in gross domestic production in the majority of Arab States. The use of beneficial S&T know-how, whether in the area of increasing quality and productivity of human capital or in maximizing the value added income of natural resource development, manufacturing and services, appears to be the best, if not the only option for improving the quality of life in the region.

Past achievements and future research trends

Although the Arab States are not well endowed with agricultural resources, their performance in food production has improved substantially in recent years. Most of the improvement has been achieved through better use of S&T inputs into the food production system rather than the expansion of resources. It is true that the region's share of total world arable agricultural land amounted to 3.8% in 1992, a figure close to its share of world population of 4.2%. However, 80% of the food produced came from 25% of its total arable land endowment, the area which happens to be irrigated. During the late 1980s the Arab States intensified the use of such improved production inputs as seeds, fertilizers, pesticides and irrigation technologies, and were therefore able to achieve productivity levels in certain crops to match the highest in the world. These achievements, however, were not without negative consequences. Much of the Arab groundwater resources, for example, have been overexploited, causing deterioration of aquifers. Another consequence has been the deterioration in the productive capacity of irrigated agricultural lands due to high salinity and to monocropping. Arab agricultural research systems have, thus far, focused their efforts on maximizing resource utilization with little regard for sustained productivity. Some states suffer more than others in the degree of deterioration of resource quality and productivity. Those endowed with large river basins have already been severely affected. On the other hand, the gap between population growth and economic growth is widening in most countries. Family planning programmes have been instituted in several Arab States but do require effective implementation to bring about more consistency between the rates of population growth on the one hand and adequacy of conditions for reasonably acceptable levels of human development on the other.

Arab mineral and non-renewable energy resources are being exploited at unprecedented rates. The development of more effective methods of mining and processing is becoming a priority. Modest research efforts to this end have already started but require strengthening in order to produce the desired impact. Research on solar and wind energy has been started in many Arab States but has focused more on the evaluation and transfer of technologies generated in environments different from those prevailing in the Arab region.

Manufactured goods have been produced, thus far, for domestic and Arab regional markets, with marginal attention given to export markets on the international scale. The emerging trade conditions are working against national trade barriers and measures that protected products of inferior quality in the domestic markets. These trends are bound to influence the scope and quality of R&D activities in manufacturing, especially in areas where the Arab States have a comparative advantage. These include tourism, petrochemicals, fertilizers, irrigation technologies, textiles and the pharmaceutical industries.

In conclusion, the Arab States do have an opportunity to improve the performance of their S&T systems to better serve social and developmental objectives. Past experiences and emerging world realities should provide policy makers with the capacity to choose more realistic options and to use more effective means of achieving the desired objectives. The emerging trends in S&T activities may be summarized as follows:

- Development of water and soil management models in order to optimize and sustain productivity of these resources, especially in irrigated production systems.
- Generation and development of technologies to desalinate brackish and sea water, conserve the quality of existing water resources and maximize the efficiency of water use in all sectors.
- Generation and development of technologies to increase the efficiency of oil and gas extraction as well as mineral mining. An increase of just 1% in the extraction of existing oil reserves means a gain of tens of billions of US dollars.
- Development of strategies and realistic intervention to bring about family planning in individual families.
- Development of instruments to promote private-sector support to R&D and technical service activities in tourism, manufacturing and marketing.
- Development of models and instruments to improve management in government bureaux as well as in private-sector manufacturing and business enterprises.
- Development of instruments and indicators to monitor and evaluate the performance of public- and private-sector universities.
- Revitalization of R&D and technical service activities through the development and implementation of realistic interventions to promote linkages among stakeholders and to apply institutional frameworks based on competitiveness and productivity of S&T human resources.

THE WORKING ENVIRONMENT OF THE SCIENTIFIC COMMUNITY

Arab scientists work under a diverse set of conditions that range from the very good to the inadequate. In rich states or in those that enjoy stable economic and political conditions, institutions usually provide working environments that attract scientists. In these institutions, scientists earn good to moderate incomes, enjoy a number of incentives and fringe benefits and can carry out their teaching, research and/or service in the community with an acceptable level of satisfaction. On the other hand, institutions that operate in countries facing economic difficulties and/or social tensions and civil disturbance suffer from a number of constraints that range from low staff income, compared with regional and international standards, to severe inadequacies in the environment required for the normal carrying out of scientific functions.

Budgets of about 30 universities and major R&D centres were analysed over a number of years. Invariably, the items most affected by cuts in budget are those that have a direct bearing on the quality of performance, and include the following:

- funds allocated for research support in universities;
- funds allocated for new books, reference materials and subscriptions to new periodicals;
- reduction in subscriptions to established periodicals;
- maintenance items;
- materials and equipment for teaching or research;
- funds for attending conferences overseas;
- new post openings for research, teaching and support staff.

With the exception of those in the Gulf States, most S&T institutions in the Arab States have suffered from low levels of funding since the mid-1980s. One consequence of this situation is the massive movement of Arab scientists in the search for better working conditions abroad. In 1990/91, statistics show that 6 800 Arab scientists, of which 89% were PhD holders, were working outside their home state but within the Arab region. This figure was equivalent to 11% of total PhD staff members in all Arab universities and R&D institutions. A second category of scientists who work outside their institutions are those employed by private sector firms or universities within their own home state. The total number of PhD staff members on leave from 25 Arab universities located in four Arab States came to 8-15% of the total staff members in each of the universities.

Statistics on Arab scientists emigrating to countries outside the region are not available. However, the US National Science Board's *Science and Engineering Indicators, 1993* put the total number of immigrant scientists and engineers from the Near and Middle East region at 1 600 in 1991. It also indicated that 29% of PhD recipients from countries of West Asia had firm plans to stay in the USA.

The impact of a temporary, and perhaps permanent, brain drain on the region has not been studied in detail. Institutions that grant leave of absence to staff members often suffer from inadequate staff : student ratios. On the other hand, some may argue that the temporary emigration of scientists has a positive result in the transfer of experiences. Thus far, however, no reliable information is available on the effects of such movement on the performance of S&T institutions in the Arab region.

ARAB INTERNATIONAL COOPERATION AND ASSISTANCE: PRIORITY AREAS

Although the Arab States have achieved various levels of development, including S&T capacity, we may identify certain common needs either shared by all states, the majority or sub-regional groupings. The following is a brief review of some of the areas in which international intervention is needed to help speed improvement:

- The provision of models of resource management has always been needed but has become urgent in recent years. The objective of management models is to improve productivity of human, financial and natural resources in order to optimize performance. Some of these tools have proved to be universal or regional and may be transferred with little modification, but others need to be developed to fit specific cultural characteristics.
- Development of S&T policy instruments is required. Higher education and research are both costly activities, and many Arab countries are not wealthy enough to afford sophisticated S&T institutions in all areas. Thus far, policy objectives are often too ambitious, if not totally unrealistic, compared to the means available. All public

universities, for example, claim three functions, each of which requires sizable funds: graduate studies, research and community service. Such objectives may be legitimate when a state has only one university. The majority of Arab States, however, have four or more universities or university-level institutions, 50% of the states have eight or more universities and the numbers are growing each year. Most of these institutions, with the exception of those operating in the oil-exporting Gulf States, are suffering from low levels of funding; finance is simply not adequate, to say the least, to achieve declared objectives. What is required is the development of policy instruments and institution performance indicators to guide policy choices and to rationalize the use of resources so as to achieve objectives through more realistic approaches.

- Promotion of dialogue among leaders is necessary. Arab universities have an association with membership that covers almost all Arab States; similarly, research councils and/or ministries of research have a pan-Arab union. Unfortunately both bodies suffer from budget deficits, a situation that has constrained their activities in facilitating dialogue and the exchange of experiences amongst S&T institution leaders. The two organizations, namely the Association of Arab Universities and the Union of Scientific Research Councils, can nevertheless still provide useful fora at which realistic approaches to S&T policy choices may be discussed. Outside support is required for meetings designed to bring about the exchange of experiences to mobilize funds in support of S&T activities, to define criteria for the measurement of accountability of research and to set priorities in the light of available resources and the critical mass needed to achieve fruitful results.

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On his return to Jordan he worked with the Ministry of Agriculture for five years before joining the University of Jordan, where he held successive posts as Associate Professor and Professor of Plant Pathology, and founding Dean of the Faculties of Sciences, Agriculture and Graduate Studies.

Dr Qasem served his country as Minister of Agriculture in 1991 and then in 1992 established himself as a full-time consultant. His consultancy work in the area of S&T education and R&D has been carried out for numerous international and national organizations including UNESCO, FAO, UNDP, the World Bank, UNEP, ALECSO, IDRC and USAID. He recently concluded a major study for UNESCO on S&T indicators in the Arab States.

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Africa

THOMAS R. ODHIAMBO

As it meets the third millennium, the continent of Africa remains profoundly influenced by three things. First is the deep sense of wounded psyche that the five centuries of diaspora and colonial subjugation have engendered, experiences whose historical run came to an end only in May 1994 when the Republic of South Africa formally abolished apartheid and became democratically free. Second was the fragmentation and parcelling of Africa into arbitrary entities by the colonial powers in the closing decades of the 19th century. This one irrational geopolitical activity spawned at least two major conundrums: it exacerbated the diverse ethnic rivalries in Africa, and it created a whole range of minuscule nation-states. Of the 53 existing African states, 22 are micro-states, each consisting of less than 5 million people, and another 12 are mini-states, each having between 5 and 10 million people only. Added to the colonial heritage of tightly controlled borders, there exist tremendous disincentives to undertake cross-border communication, cooperation and trade. Indeed, there are much stronger historical linkages with the former metropolitan powers than with neighbouring African countries. And third, ever since the early 1970s, Africa has become steadily impoverished, even in the face of its enormous range and extent of natural resource endowments; and has become greatly indebted to bilateral creditors (64% of all debt stock) and multilateral financial institutions (MFIs), especially the World Bank, the African Development Bank (ADB) and the International Monetary Fund (IMF), which account for 19% of the total debt stock. Existing debt reduction strategies in Africa have proved inadequate, and have not stemmed the steady growth of the external debt stock; yet MFIs have opposed any writing-off of their debts, or even of their being rescheduled. Consequently, in reality, the African external debt has become unrepayable.

It is in this context that the critical role of science and technology (S&T) in the future development of Africa, and in its commitment to the growth of scientific knowledge worldwide, should be seen.

HIGHER EDUCATION IN SCIENCE: NEW TRENDS

The African university system has been in ever-deepening crisis since the mid-1970s. It is the material side of this crisis that is immediately obvious: the overcrowded hostels, lecture rooms and laboratories; the poorly stocked and outdated libraries; scantily equipped laboratories; workshops with non-functioning machinery; overworked lecturers, who are so underpaid that they have to take a second occupation in order to survive; a tiny group of postgraduate scholars, who spend two to three years beyond the normal period before they can successfully complete their studies; frequent student riots, and occasional staff go-slows; and an overwhelming administrative bureaucracy. What is not so visible to the casual observer is the creeping irrelevance of the contemporary African university to the community and society in Africa.

In 1972, the Association of African Universities (AAU) convened a major conference in Accra, Ghana, on the theme Creating the African University, to consider the then emerging issues only a decade after the political independence era had begun in earnest. The conference decided that its principal goal was to re-design the university in Africa as a 'development university', and, in this context, to carry out five special functions: to create an African academic community; to develop curricula relevant to African problems, economy and society; to end the academic and administrative dependence on universities belonging to the former metropolitan powers; to introduce, for the first time, the teaching of African languages in African university institutions; and to become involved in national development.

While enormous progress has been made in implementing the 1972 AAU vision of the African university, new emerging issues have taken the centre stage. Increased pressure for university undergraduate enrolments in the face of decreasing university budgets; the rise of graduate unemployment in the face of escalating liberalization of the economy; worsening confrontation between students and university administrations, and between universities and governments in the context of political democratization; and the vital need of a critical mass of postgraduate specialists and entrepreneurs in the deepening marginalization of African economies – all these issues led the AAU to convene a second review of the African university in the context of this new geopolitical and geoeconomic environment.

Thus in January 1995 an international conference of heads of nearly 100 African universities was held in Maseru, Lesotho, on the theme, The University in Africa in the 1990s and Beyond, with the goal of proposing practical measures to reverse the decline of the African university and its role in Africa's development (AAU, 1995). The conference realized that knowledge-based production and economic development had become the norm the world over and that, in this and other respects, the old models of the university still current in Africa had become anachronistic; that the new-found African university must address the pressing needs of development and society, through the power of knowledge; that learning had truly become a life-long process; and that a major objective must be to repair the damaged public perception of the African university as a driving force for the transformation of that society. As one consequence of the Maseru review, the AAU is in the process of establishing a multi-campus graduate training and research programme in key areas of development, starting with environmental management and biotechnology.

The donor community has watched these recent movements, and taken its own parallel measures. In June 1995, a small group of donors convened an international conference in Uppsala, Sweden, on the theme, Donor Support to Development-Oriented Research in the Basic Sciences (International Science Programs, 1995). Their concern was that, in the rush of developing countries approaching S&T solely from the point of view of its utility in technological innovations, the well-springs of new scientific knowledge might tend to dry up in the long term. A corrective measure therefore needed to be put in place, by strengthening the basic sciences (biology, chemistry, physics and mathematics) as a basic foundation for indigenous education and technology. The Uppsala conference declared that a 'foundation in the basic sciences is essential for all research in the applied sciences and for long-term development'; that 'a strategy for support to the basic sciences should be articulated by each developing country and its national institutions, and should be geared to solving specific development problems in that country'; and that 'research questions within the basic sciences must be chosen judiciously with the future development needs of the specific country in mind'; and went on to recommend action in five areas:

- Capacity building in the basic sciences, developing first-class cadres in each country through problem-driven research.

- Support for research and higher education in the basic sciences through, for example, support for capacity building in molecular biology being included in the funding for a health-related project.

- Increased coordination and cooperation among donor agencies within each country, as has been effectively demonstrated by the coordination efforts of Eduardo Mondlane University in Mozambique. Such donor cooperation is required for regionally organized postgraduate training programmes and South-South training and research programmes.

- Putting in place modern information technologies (e.g. CD-ROM systems and e-mail linkages) so as to have easy access to library and documentation resources.

- Undertaking a comprehensive rehabilitation of research and teaching infrastructure in most African universities, and their proper re-equipping, as a critical precondition for the development of capacity in S&T.

Rehabilitation and re-equipping of the S&T functions of the major universities in Africa, somewhere in the order of 200 entities, will probably require at least a decade and an investment of some US$6.0 billion. This is a vast sum for African governments who own 98% of these entities and wield control over their governance and management. Because of their very conservative nature, turning these entities into dynamic motors for change is likely to prove a herculean task, demanding an unusual commitment.

All these recent attempts at re-engineering the African university are a means of ensuring the full development of African talents and of bringing a more entrepreneurial spirit into these developments. These include a determined attempt to integrate women fully into the university life as students and staff. At present, according to the *UNESCO Statistical Yearbook 1993*, female university enrolments in the natural sciences, computer sciences, medicine and agriculture are low (from 8% to 40%), while those in engineering sciences are lower still and generally less than 10% (see the chapter by Professor Lydia Makhubu entitled Women in science: the case of Africa, in this *Report*).

Because of the pivotal position of human resources in the modern economy, tertiary education, comprising universities and polytechnics, is one major contribution to the solution to Africa's current development crisis.

An African Research University

Under its Priority Africa Programme, UNESCO is funding a project at the Research and Development Forum for Science-Led Development in Africa (RANDFORUM), based in Nairobi, Kenya, in which a small planning group is designing a pilot scheme for establishing a different model of the African university – a small, highly specialized, African Research University. The main campus of such a Research University is expected to be an existing centre of excellence in a strategic priority field for Africa, such as tropical medicine, computer software development and applications, and marine and geological sciences, which will be linked to six or more prospective centres of excellence throughout Africa. Such a network, involving distance education programmes, will then constitute the Research University, which will concentrate on postgraduate education, development-oriented research, and consultancy work, and establish strong functional linkages to the host community and the productive sector. With such a remit, the Research University will be highly relevant to the problems and needs of the productive sector, the community and the national development goals, while contributing to the world's knowledge endowments and having a participatory role in the integration of Africa. This new university model will become public in mid-1996.

THE STRUCTURE AND ORGANIZATION OF SCIENCE IN AFRICA

Another contribution to the long-term solution of Africa's current crisis is to be found in a demand-driven, mission-oriented organization of Africa's science enterprise.

The emerging typology of the structure and organization of S&T in Africa seems to have following format:

- *At the regional and continental level*, S&T takes its political cue from the Organization of African Unity (OAU) and its technical supervision from the United Nations Economic Commission for Africa (UNECA), under the umbrella of the OAU Scientific, Technical, and Research Commission (OAU/STRC), as described in the UNESCO *World Science Report*

1993. Since then, the Scientific Council for Africa (SCA) has been resurrected (in mid-1994), under OAU/STRC auspices, as the OAU's main S&T policy advisory organ, after lying dormant for nearly 15 years. Furthermore, S&T policy protocols are being formulated within the charter instruments signed in Abuja, Nigeria, in 1991 establishing the African Economic Community by the year 2025.

- *At the national level,* there has grown since the early 1970s, a government-initiated national S&T policy advisory agency, or its variants, on a model pioneered by UNESCO in the early years of political independence, to replace colonial structures which formerly answered to a metropolitan policy body for direction and monitoring. Often the university has played a substantial role in these bodies. In some cases since the early 1980s, following on the Vienna Conference on Science and Technology for Development in 1982, some African governments have established Ministries of S&T (or their variants), while maintaining the national S&T policy advisory organ as a separate advisory mechanism. In almost all cases, industry has not played a significant functional part in formulating policies, or in their review. In principle, the S&T policy should be a strategic element in the national development plan and its implementation; but it rarely is, except in the competitive production of the major export commodities.

- *At the private sector level*, the essential innovations are sourced either from the home-based scientific research and development (R&D) establishments of the foreign corporations, or are purchased in the form of capital goods or turn-key projects. There are an insignificant number of problem-solving R&D efforts undertaken by manufacturing industries within most African countries.

- *At the intellectual and professional level*, a range of institutions has grown in the last three decades – in most cases as national branches or affiliates of long-established professional fraternities and chartered institutions (for example, for the medical, banking, accountancy, legal and management professions); or as nodes in international networks (such as for the academic research community, the scientific societies and the engineering associations). Such linkages are very much outward looking, taking their professional reference points from worldwide, industrial country criteria.

- *The academy of science*, as an elite organization purposely positioned to recognize excellence and achievement, as well as to promote scientific advancement, is a recent growth in the continent (Odhiambo, 1983). The majority of the national academies of science, such as those of Morocco, Nigeria and Kenya, have taken the European historical model of being private organizations of academicians, of publishing journals, arranging discourses and conferences, awarding prizes for singular scientific achievement and advising governments on S&T policy whenever called upon to do so. The Ghana Academy of Science took a different path, starting off four decades ago in the executive agency mould of the former East European academies of science, with all research institutions coming under its purview. The Ghana Academy has moved away from this model, but still enjoys strong links with the government. The African Academy of Sciences, established in December 1985, is an altogether different species. It is a members' organization at the continental level, probably the only one of its kind. It is not a federation of national academies, nor an apex body; its main remit is one of fueling Africa's science-led development, through the promotion of excellence and relevance, and through its own programmatic activities, such as those on capacity building (on soil and water management, on forestry research, and women-in-science internships, for example). It is one of the independent sector institutions now beginning to emerge in Africa.

All these S&T structures have yet to tackle, in a systematic, long-term way, the issue of intellectual property rights, as Africa positions itself for competitive production and marketing in both the intra-African and international markets. Indeed, even though the *Organisation africaine de la propriété intellectuelle* (OAPI), based in Yaoundé, Cameroon (established in 1962), and the African Regional Intellectual Property Organization (ARIPO), based in Harare, Zimbabwe (established in 1976), were founded to initiate new mechanisms which did not depend on the original registration of inventions, innovations, trademarks and industrial designs being done in the former metropolitan capitals, the operational effectiveness of the new, Africa-based mechanisms has still to make itself manifest (Ojwang', 1989). Further, the new concerns arising from the United Nations Conference on Environment and Development, held in Rio de Janeiro in 1992, especially those relating to biodiversity, gene patenting and chemical prospecting, and the concerns stemming from the completion of the Uruguay Round of the General Agreement on Tariffs and Trade (GATT), particularly those relating to the obligations of each state to protect industrial property in its territory, are matters now requiring the urgent attention of Africa, especially in relation to the proper exploitation of its own biological endowment and its immense corpus of community-based traditional knowledge, for example in giving a rational scientific basis to herbal medicine.

The key issue in Africa at the moment is not the protection of foreign patents and other industrial property (trademarks, utility models, brand names and industrial designs); these are already well catered for through the various conventions to which African states are individually party. The crucial concern is how Africa will provide stimulant incentives to its own inventors, innovators, entrepreneurs and venture capitalists in order to create, produce and market competitively Africa-specific solutions for its demand-driven technological needs.

Already, private initiatives have led to the formation of inventors' associations in Congo, Côte d'Ivoire, Egypt, Kenya, Morocco, Senegal, Sudan, Tanzania, Zaire and Zimbabwe. The *Association des inventeurs du Congo* is particularly dynamic, promoting the inventive work of young people, putting up exhibitions of inventions and innovations and operating information programmes for the general public. Nonetheless, a synergistic bridge with the productive sector has still to be constructed and made enduring.

RESEARCH EXPENDITURE

Funding for R&D in Africa arises from four principal sources:

- *The government treasury*, for the support of research institutions, which are overwhelmingly parastatal organs of the government. Overall government support for R&D in Africa is the lowest compared with any other region in the world, as highlighted in the *World Science Report 1993*. Yet this government funding is by far the largest source of finance for R&D on the continent, except perhaps in the agricultural sector (Bhagavan, 1989), as exemplified by R&D funding in Ethiopia over a 10-year period from 1974 (see Table 1).
- *The trade itself through R&D levy*, as has been so successfully accomplished in the sisal, pyrethrum, coffee and tea industries. For instance, the Tea Research Foundation of East Africa mobilizes its entire R&D funding through a levy exacted from each tea producer, whether at the peasant scale or the plantation level; and the producers as a body participate fully in developing the R&D agenda, all the way from production to the fully processed and packaged product. As a consequence of this demand-driven, problem-solving, participatory approach, and the efficient marketing system which has been operated over the last half-century including an effective tea auction exchange at the

TABLE 1
BUDGET ALLOCATION FOR R&D IN ETHIOPIA BY THE ETHIOPIAN GOVERNMENT AND FOREIGN DONORS FOR THE PERIOD 1974-75 TO 1983-84

Sector	R&D budget: Total (Birr millions)	R&D budget: Donor support as % of total
Food and agriculture	98.1	53.2
Industry and technology	6.7	3.6
Natural resources	49.8	27.0
Health	16.9	9.2
Construction	5.9	3.2
Education and culture	0.7	0.4
Others	6.2	3.4
Total	**184.3**	**100.0**

Source: Bhagavan, 1989.

major East African sea-port, Mombasa, the science-led East African tea industry is highly competitive on the world marketplace.

- *The donor community*, through the United Nations Development Programme (UNDP) and the United Nations specialized agencies (UNESCO, UNIDO, FAO, WHO, etc.); the OPEC Fund for International Development and other regional development organizations (for example, the Arab Fund for Economic Development); the technical assistance funds of the African Development Bank (ADB) and the World Bank; foreign national development agencies (for example, Canada's International Development Research Centre (IDRC), the Japan International Cooperation Agency (JICA) and Sweden's SAREC); the private philanthropies (the Rockefeller Foundation, the Carnegie Corporation of New York, the Nuffield Foundation and the Sasakawa Foundation); and self-standing international funding mechanisms established by a number of institutions, such as the International Foundation for Science (for aquaculture, livestock production, crop science, and forestry and agroforestry), the Third World Academy of Sciences (TWAS) (for equipment spare-parts, scientific conferences and South-South research cooperation) and the African Academy of Sciences (AAS) (for capacity building in soil and water management, forestry research and research into female education).

- *Loan funding*, through specific loan programmes negotiated with the World Bank and the ADB. Recent loan programmes have covered higher education (Nigeria and Kenya), agricultural R&D (Sudan and Uganda) and rice improvement (countries of the Economic Community of West African States, ECOWAS). Such loans have been negotiated under extremely low interest rates, of about 0.5-1.0%, for 25-40 years, with a grace period of 5-10 years. With the extraordinary level of indebtedness of Africa to external creditors, including the MFIs, this low-interest facility is the only remaining possible source for substantial capital sums for the rehabilitation of the R&D infrastructure, which has been so eroded over the last two decades, and for initiating new strategic national development programmes. Nonetheless, technical assistance grants would be preferred, even though they are relatively small in volume. In the period between 1974 and 1992, the ADB affiliate for low-interest financing, the African Development Fund (ADF), disbursed a total of 517.14 million FUA (i.e. about 6.5% of the total ADF loans and grant approvals over the period) to all African states and R&D institutions. (Each FUA is a unit of account equivalent to slightly over US$1.00 and to one Special Drawing Right, the unit of account of the IMF.) There has been a sharp increase in technical assistance grants from the early 1980s (ADB, 1993).

With increasing jeopardy of government funding for R&D in general in Africa, the constriction of funding from the donor community so evident now, and the very small contribution to industrial R&D by either the government or the manufacturing industry, new forms of more assured R&D funding are beginning to emerge within the continent itself.

At the national level, several countries (Ghana, Botswana, the Republic of South Africa, etc.) are establishing government-supported foundations to finance selected areas of R&D as well as the required capacity building for these fields. Annual allocations are provided to these national foundations from their treasuries, and at the same time they are encouraged to attract funds from the private sector.

At the continental level, a new endowment funding system is being created, in the form of the African Foundation for Research and Development (AFRAND). It was chartered at a ceremony attended by several heads of state on 22 July 1994 in Maputo, Mozambique, in the course of the second annual session of the Presidential Forum on the Management of S&T for Development in Africa. Its governing organs have now been inaugurated; and it will start its operations at its headquarters in Lilongwe, Malawi, in early 1996. It has recently initiated its fund-mobilization programme: this includes the collection of a one-time grant from each supporting African state; grants from philanthropic and development bodies; the establishment of a contributory fund for all partners in Africa's science-led development, whether they be individuals, institutions or corporations – the African Millennium Trust Fund; and negotiations towards the Debt-for-Science Swap (DFSS) scheme in respect of a formally allocated portfolio of external debt negotiated for such a purpose. Most of these funds will be prudently invested as an endowment fund, the income from which will be allocated to priority programmes of strategic importance to Africa.

If AFRAND does become operational and successful in its chosen role as the premier fund mechanism for the in-coming science-led development paradigm in Africa, it will have achieved the epoch-making breakthrough that the continent uniquely needs. AFRAND is an element in the growing independent sector, just as the originators of the continent-wide consultations that began in 1988 and led eventually to its establishment – AAS, TWAS and the International Centre of Insect Physiology and Ecology (ICIPE) – are also part of the independent sector. Part of the strength, as well as promise, of AFRAND lies in the fact that there already exists a powerful instrument for continually nurturing an enabling geopolitical environment for R&D and science-led development in Africa, namely the Presidential Forum; and also that all the main streams of economic and development partnership are directly involved in the African Foundation through three think-tanks it has created – the Roundtable of Science Advisors for Science-Led Development in Africa, the Roundtable of Technology-Oriented Entrepreneurs in Africa and the Roundtable of Capacity Building Leaders in Africa. Another prospective strength is that AFRAND will endeavour to mobilize African brainpower resources worldwide through its programme on Distressed and Expatriate Scientists and Scholars from Africa (DESSA), the plan of implementation for which was endorsed by the third annual session of the Presidential Forum, meeting in Kampala, Uganda, on 24-25 July 1995.

At the international level, two recent initiatives are of especial significance. The first is the establishment, some five years ago, of the African Capacity Building Foundation, based in Harare, Zimbabwe, by the World Bank, UNDP and ADB. Although its main concentration is on capacity building for Africa's management of its economy, it contains obvious areas of convergence with AFRAND and Africa's overall drive to promote R&D. The second initiative was authored by UNESCO, which two years ago created an International Fund for Technology Development in Africa, under its Priority Africa Programme, with an initial donation of US$1 million, and which is expected to attract contributions from other donors. UNESCO has started using the net income from this fund to finance innovative projects under its university-industry linkage programme (UNISPAR).

POLICIES FOR S&T

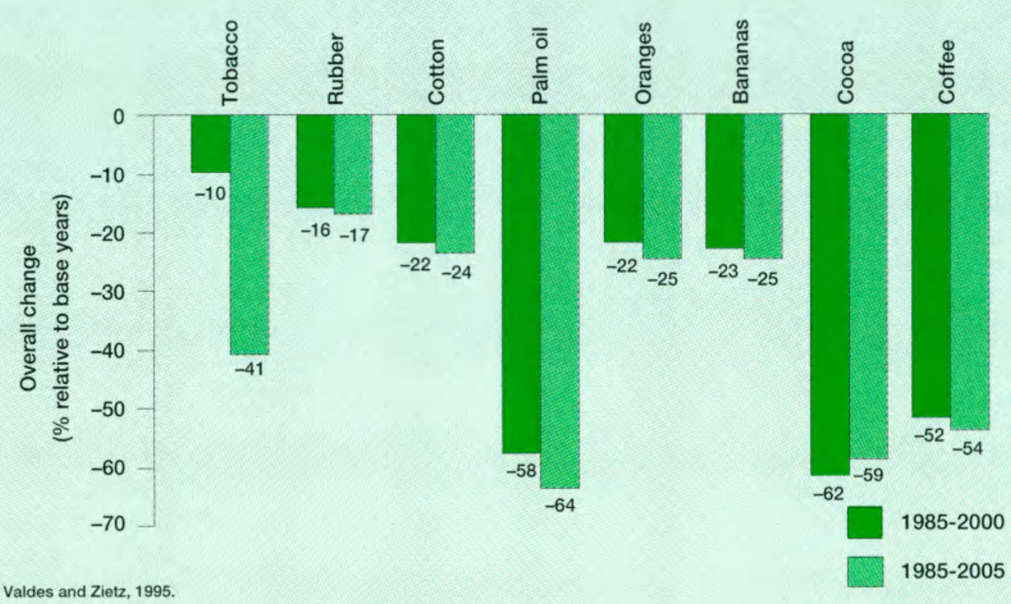
The S&T policies that African states have adopted in the last three decades have been concerned largely with science rather than with technology. Perception is gaining ground that these two facets of the same policy entity are in effect 'two dancing partners who each have their own steps although dancing to the same music', and that technology has been fending for itself without any manifest influence from science (Aju, 1994). For example, of the 25 major federal research institutes in Nigeria, only four deal with industrial research, and they have wielded little influence on Nigeria's economic development, which still depends on imported technology and raw materials and intermediate goods for the manufacturing industry.

Going further, nearer to the root of the problem, it is quite evident that Africa's S&T policy researchers and analysts tend to have weak connections to industry (Tiffin and Osotimehin, 1992). For example, although national agencies for S&T policies have been established in some of the Southern African Development Community (SADC) countries – the Botswana Technology Centre in Botswana, the National Research Council in Malawi, the Tanzania Commission for Science and Technology in Tanzania, the National Council for Scientific Research in Zambia and the Research Council of Zimbabwe, all reporting through cabinet ministers, except in Zambia where the Prime Minister is the chairman of the Council – they do not seem to have brought about a transformation in the direction and content of the nations' development. They have limited their activity to coordinating research, with only a limited functional linkage to the productive sector shown in the case of Zambia, where the mining industry funds research and infrastructure at the School of Mines at the University of Zambia. They lack expertise and experience in developing industrial extension services, industrial consultancy services, strategic planning and budgeting for S&T, and choice and assessment of technology; and they do not have a regular programme for S&T policy studies at the microlevel, for sector-specific or plant-level policy formulation (Tiffin and Osotimehin, 1992).

Yet Africa must move away from over-dependence on the export of basic commodities. During the period 1900-86, the prices of food staples declined at an average annual rate of 0.35%; 0.54% for non-beverage foods and 0.82% for non-food agricultural products. During the period 1950-92 the decline in food prices accelerated to 1.3% per year. Future forecasts indicate that world prices for agricultural products (Figure 1) will continue to decline in real terms, although future gains from new technologies could change the picture somewhat (Valdes and Zietz, 1995).

In the SADC countries, minerals are the second

FIGURE 1
PREDICTED CHANGES IN WORLD PRICES OF TROPICAL AGRICULTURAL PRODUCTS



Source: Valdes and Zietz, 1995.

mainstay of the economy, with the Republic of South Africa occupying a dominant position in this sector. The region is making an entry into the iron and steel industry, as well as the fabrication of metal products and rolling stock (the Republic of South Africa, Zimbabwe, Zambia and Tanzania). A coherent natural resource-based industrialization programme has still to be formulated by the region, and put into the larger African context. The attempt to do so through the UNECA-sponsored, UNIDO-programmed Industrial Development Decade for Africa, which began in 1981 and is now in its second incarnation, has not made much of a difference as yet. The on-going industrialization processes in Morocco, Egypt, Kenya, Zimbabwe and Mauritius are self-generated. In the case of Mauritius, it is being accomplished through a bundle of S&T policies which are sharply focused and the result of political commitment by the state. The policy bundle includes: capacity building at the tertiary level of solely those fields of direct relevance to the nation's industrialization programme; the establishment of export production zones (EPZs), with highly attractive incentives, including those of infrastructure construction and tax-exemption; the enactment of off-shore financial sanctuaries; the operation of joint ventures, particularly with emerging Asian multinational corporations in selected strategic fields within manufacturing; and the deliberate programme of diversifying the economy away from the export of basic commodities, such as cane sugar.

FUTURE TRENDS IN RESEARCH IMPORTANT FOR THE CONTINENT

It is ironic that the African continent so rich in natural resources, both biological and mineral, is yet deeply impoverished, while other nations and foreign corporations operating in Africa have become wealthy on these selfsame resources. Africa, therefore, needs to start from this reality, as it adopts a science-led, technology-dominated strategic approach in its future economic growth and social development.

The final GATT, which was concluded in 1994 after seven years of negotiations and which led to the establishment in 1995 of the successor mechanism, the World Trade Organization, promises a substantial boost for world trade. But it is unlikely particularly to favour Africa, since Africa has conventionally relied on the export of raw materials and primary commodities, which already attract only minimal tariffs or none at all, while its hitherto preferential treatment regime through the Lomé Convention will begin to be dismantled within the next decade.

In adopting a science-led development approach in order to be competitive in the export of processed or manufactured goods and services based on its natural resource endowment, Africa needs to assume a competitive production and marketing posture by implementing at least five measures:

- The continent must, in moving away from traditional dependence on primary commodities (from agriculture, forestry, fisheries, mining), carefully identify niche markets for value-added products and services, and non-traditional items for knowledge-intensive production.
- The continent must vastly extend and upgrade its S&T infrastructure as a matter of priority, and keep it at an efficient and cost-effective level through whatever feasible mechanisms are available, whether government, private or a mixture of both.
- African governments must abolish legislative and procedural structures that hinder investment from domestic, intra-African and foreign sources into the national and regional economies. It is only when these restrictive practices are phased out permanently that the vibrant informal domestic enterprises and their savings can seek more formal trade and banking outlets, which will allow African multinational enterprises to begin to emerge. In this latter respect, the Standard Chartered Bank has undoubtedly the most extensive branch network in Africa, since it established itself in Africa some 130 years ago, followed by the *Banque Nationale de Paris*, which has an extensive network in French-speaking Africa. Ecobank, founded in 1990 by the Federation of West African Chambers of Commerce, with affiliates in Benin, Côte d'Ivoire, Ghana, Nigeria and Togo, is likely gradually to cover the entire ECOWAS region (Sudarkasa, 1993). These pioneering banks in their multi-country banking endeavours have recently been joined by the ADB-sponsored African Export-Import Bank (AFREXIMBANK), based in Cairo, Egypt, which is initially capitalized at US$100 million.
- Africa needs to diversify the destinations for its exports. Currently, the continent is doing most of its business with its former metropolitan powers – Belgium, France, Germany, Italy, Portugal and the UK, and by extension the European Union. Since political independence, the USA has come on strongly, purchasing 20% of African exported goods (by 1991), followed in the second place by Germany. Japan is beginning to emerge as a significant export destination; but Asia as a whole is a long way from being a major two-way trading partner; so are South America, Eastern Europe and Euro-Asia.
- Africa needs rapidly to develop its capital markets, which (apart from the Johannesburg Stock Exchange) are still very fragile and illiquid (Sudarkasa, 1993). While the Johannesburg Stock Exchange lists over 700 corporations and is capitalized at over US$180 billion, the other 12 existing, mostly very young, stock exchanges – in Cairo (Egypt), Lagos (Nigeria), Nairobi (Kenya), Bulawayo (Zimbabwe) and the very small ones in Casablanca (Morocco), Abidjan (Côte d'Ivoire), Accra (Ghana), Port Louis (Mauritius), Gaborone

(Botswana), Lusaka (Zambia), Lomé (Togo) and Kampala (Uganda) – are capitalized in total at a mere US$6 billion with listings of only about 1 000 corporations. Even though these security exchanges are relatively inactive, the International Finance Corporation (IFC), a member of the World Bank Group, considers them amongst the best performers in the world: for example, the Zimbabwe securities appreciated 90% (in 1990) in dollar terms over their value the year before (and in national currency terms, 163%). Clearly, the African capital markets are poised to be significant players in the mobilization of investment resources, and hopefully in pre-investment R&D in technology-dominated enterprise fields.

Perhaps one of the principal areas in which this integrated framework will be put into operation is in the whole field of traditional knowledge-based herbal medicine (Okogun, 1985). This recognizes that a disproportionately large share of healthcare (about 80%) is delivered by way of herbal medicine in the developing world (WRI, IUCN and UNEP, 1992). Coupled with this it is acknowledged that the major tropical diseases, such as malaria, leishmaniasis and trypanosomiasis, are not being adequately addressed by the major foreign multinational corporations, because the African market is perceived to be small and impoverished. And, third, it is recognized that the rich African traditional knowledge base has not been exploited systematically, nor in the context of an organic partnership between the traditional inheritors of this knowledge and the modern analytical and synthetic chemists, pharmaceutical chemists and medical practitioners, as the Chinese have done (Eisenberg and Wright, 1995). If such a programme were to come into being, through the development of the OAU/STRC-sponsored African Pharmacopoeia project for instance, or through the initiation of a biotechnology-related enterprise, it could prove a strategic initial point for a modern start-up in Africa's industrialization – different from that of the current Asian industrialization model, or the original 19th century European Industrial Revolution, both of which were largely founded on heavy manufacturing industry.

FIELDS RIPE FOR INTERNATIONAL COOPERATION OR ASSISTANCE

In July 1993, the Swiss government, in cooperation with the Conference of the Swiss Academies, produced a strategic policy on future cooperation between Switzerland and the developing world, which could have pivotal impact, particularly since it chose Africa as its principal area of concern (Swiss Federal Department of Foreign Affairs, 1993). The policy laid down some fundamental principles for the prospective Swiss-African cooperation: that a special programme on research partnerships would be developed between the two parties; that deliberate interest would be taken in networking arrangements, for the sake of cost-effectiveness as well as for reasons relating to Switzerland's own self-interest; that, because of difficulties in mobilizing adequate funding for research by African graduates returning to their countries, the programme would encourage the allocation of medium-term funding for research for such qualified returnees; and that incentives would be created for the promotion of development-related research. These elements of a new prospective compact between Switzerland and Africa have still to be tested in an environment for consensus that should be built up between the two parties; but this partnership model is already a sufficiently significant departure from the conventional aid and technical assistance model that it justifies close consideration.

It is under a variation of such a partnership arrangement, of a long-term nature, that international cooperation can be productive. For one thing, most of the major concerns of the African development community are not necessarily within the priority areas of the industrialized countries. For another, the problems are usually of a very long-term span. And, thirdly, conventional development aid has virtually failed; and one is obliged to consider a different basis for a more synergistic, organic partnership and joint ventures in the S&T field – between African countries, between Africa and other developing regions, between Africa and the newly industrializing countries the world over and between Africa and the established industrialized countries.

The problem areas that are ripe for such international cooperation, and where seed money can be critically placed for principal priority fields, can only be listed here in a very summary form. They include the following six areas:

- Tropical diseases, including those caused by the emerging arboviruses, such as Ebola virus and onyong'-nyong' virus, and the major vector-borne diseases such as malaria.

- The re-capitalization of the fragile, often degraded tropical soils, which need long-term, slow-release fertilization with phosphorus, in order to prime them to receive nitrogen and other fertilizers for enhanced crop and forage husbandry.

- The relative poverty of the continent in fresh water, linked to its periodic long-run droughts every 10 years or so which can be traced back historically and geologically to at least 60 000 years ago. These also have an impact on the continent's frequent famines, locust plagues and disease epidemics, and the widespread transhumance pastoralism requires innovative and environment-friendly mechanisms for water management, its efficient harvesting and the effective utilization of micro-water bodies for the generation of hydropower for small human settlements.

- Harnessing of solar energy in a more effective manner, beyond the conventional voltaic cells.

- Biotechnology in relation to the enhancement of agricultural productivity, health, environment management and the evolution of new materials.

- The development of new materials for vastly increasing economically feasible human settlements for both rural and urban areas, under tropical and semi-arid conditions.

The important factor dampening such international cooperation is that Africa, as a partner, is constrained by a weak financial framework. Certainly, most governments will be shy of long-term commitments which will take them away from their on-going obligations to national S&T programmes, or which will intrude on their sovereignty as has often happened in the past. Thus new instruments will need to be fashioned, perhaps through the African-based independent sector.

REDIRECTION OF DEFENCE RESEARCH

While the world is preoccupied with the issue of transforming the military establishments – of both defence R&D and military industrial production – to civilian R&D and industrial production, the continent of Africa is preoccupied with the vast problems of demilitarizing societies and the demobilization of civil-war era armies in nearly 40% of African states. The only two African states with significant defence R&D budgets are Egypt and South Africa (the latter for propping up the now extinguished and discredited apartheid regime).

Three years before South Africa entered into the democratic mould in 1994, it dismantled its own small nuclear weapons stockpile and R&D programme, just before it adhered to the Nuclear Non-Proliferation Treaty in 1991 (Collina, 1995). Nevertheless, it should be noted that the state-owned arms venture, Denel, is travelling the world seeking new partners to supplement its skills in the design, development and manufacture of export-quality products in the aerospace field, especially in the upgrading of attack helicopters and similar armaments. Indeed, in recent statements, the Republic of South Africa, through Armscor, is actively seeking ways of trebling its arms exports (Cock, 1994). For that purpose, it is seeking the lifting of the United Nations embargo on its arms trade, and to become a member of the Missile Technology Control Regime.

CONCLUSION

The strongest impression from a bird's-eye view of the African S&T scene is that, despite the civil turmoil and economic crisis presently engulfing Africa, the continent is showing plenty of initiatives to seize the promise of S&T and thereby avoid the hopelessness that loss of development would create. It will be most interesting to see what position is attained in this endeavour as we move closer to the eve of the 21st century.

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Professor Odhiambo's long and distinguished career has been marked by many fellowships and honours, including the Albert Einstein Gold Medal of UNESCO awarded in 1991. He has written widely on scientific research, and his publications range from science readers for children to monographs on development and science policy in Africa.

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South Asia

A.R. RAJESWARI

INDIA

Scientific thought and innovative ideas relating to technology have been an integral part of Indian culture and the basis of its civilization throughout history. It was only after Independence, however, and through the vision and wholehearted support of Indian leaders, that science and technology (S&T) was developed in a planned way as a major force for social and economic change. Such vision was summarized in the words of India's first Prime Minister, Jawaharlal Nehru: 'It is science alone that can solve the problem of hunger and poverty. The future belongs to science and to those who make friends with science.'

The S&T system

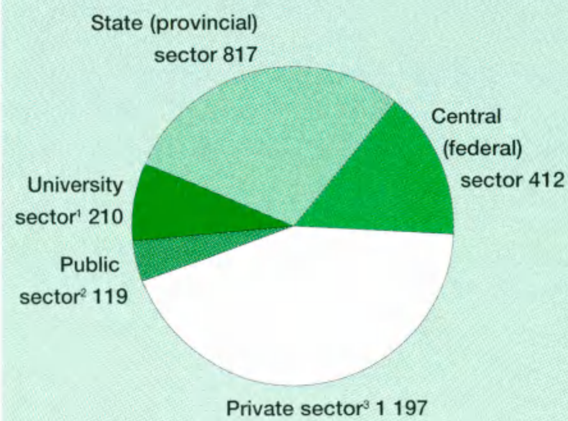
Science and technology activities in India are undertaken by a whole range of institutions and laboratories, which may be classified broadly within the following sectors:

- central (i.e. federal) government;
- state (provincial) government;
- higher education;
- public-sector industry and joint-sector industry under the administrative control of central and state governments;
- private-sector industry;
- private non-profit institutions and associations.

In all, there are some 2 750 Indian institutions performing research and development (R&D) activities, and their distribution by sector is indicated in Figure 1. The extent of S&T efforts in the different sectors varies both in terms of amount of resources deployed for S&T activities and the type of activities undertaken.

In addition to these institutions, the country has several major networks and systems, plus information and documentation centres such as the Technology Information Forecasting and Assessment Council (TIFAC), the National Informatics Centre (NIC) and the National Information System for S&T (NISSAT), to provide S&T information and a variety of allied services.

FIGURE 1
INDIAN R&D INSTITUTIONS BY SECTOR



1. Includes deemed universities, institutes of national importance and agricultural universities, but excludes 7 513 other smaller colleges.
2. Includes only in-house R&D units of central public-sector undertakings.
3. Includes in-house R&D units of private-sector industry and scientific and industrial research organizations recognized by the Department of Scientific and Industrial Research (DSIR).

Source: *Directory of R&D Institutions, 1994*, New Delhi: Ministry of Science and Technology.

S&T planning

The integration of S&T within national socio-economic planning is the responsibility of the Planning Commission. The approach and thrust to S&T planning have been more focused and sharpened over the successive five-year plans, culminating in the Eighth Plan (1992-97).

S&T funding

The central (federal) government ministries in general and the major scientific departments and agencies in particular are the main vanguards of national research effort in India. Funding to this sector is through budget allocations according to the recommendations of the Planning Commission based on the in-depth discussion of S&T programmes, both ongoing and new, of various ministries and departments identified by S&T working groups. The ministries and agencies allocate funds to their research institutions and laboratories. In addition, the latter receive extramural funding for sponsored projects, though in small measure. All the states and union territories have set up state S&T councils and separate departments of S&T to promote science. The planned outlay for the state S&T sector is decided by the central Planning Commission after in-depth discussion with the state S&T departments and S&T councils of their proposed programmes. In addition, state governments provide S&T funds in the areas of agriculture, rural development, energy, etc. to research institutions under their respective departments. The total planned outlay of the state governments is made up of the state's own resources and assistance from central government.

The financing of S&T in public-sector industry is both from its own sources and also from central (federal) government administrative ministries and departments. Private-sector industry finances its own R&D activities, as well as sponsoring non-profit research institutions. The higher education sector in India receives both extramural and intramural funding for S&T activities. The extramural funding is derived more or less from the central government S&T departments and agencies, whilst intramural research funding is obtained from the University Grants Commission (UGC), a body under the Department of Education of the Ministry of Human Resource Development. Extramural funding is small, amounting to only 2% of total national R&D expenditure.

Extramural funding goes largely to the higher education sector and, to a smaller extent, to national laboratories, and is provided for sponsored research projects approved by high-level committees. Industry hardly funds any research in the higher education sector. Due to the small flow of funds for R&D between various sectors, the share per sector of R&D expenditure by source and by performer in India is more or less the same.

Budget allocations are made for the five-year period and are monitored annually; they comprise plan and non-plan components. The plan allocation is for work on projects and invariably for new activities, whilst the non-plan allocations cover wages, maintenance and other routine expenditure.

S&T policy

A conviction of the importance of S&T both for its own sake and as an engine of national development was reflected in the formulation of the Scientific Policy Resolution (SPR) in March 1958. Included in the aims of the SPR were: to foster, promote and sustain scientific research; to ensure an adequate supply of scientists of the highest quality and to recognize and reward their work; and in general to secure for the people of India all the benefits that could accrue from the acquisition and application of scientific knowledge.

Having realized the importance of technological choice in the context of economic, social and cultural factors, the government adopted the Technology Policy Statement (TPS) in January 1983. The aims of the Statement, among others, were to attain technological self-reliance; to make maximum use of indigenous resources; to provide maximum gainful employment; to develop technologies that are internationally competitive; and to reduce demands on energy. Technology policy is under revision in the light of the changing economic and industrial scene. A New Educational Policy, revising the earlier policy of 1968, was adopted in 1986; its aims were to improve the educational system and to fulfil the needs of society in keeping with technological developments; to redesign courses and programmes of higher education better to meet the demands of specialization; to enhance support for research in the universities and ensure its high quality; and to develop interdisciplinary research. In addition, the government has adopted policies on industry, trade, computers, software and information, all of which are related to the S&T policies described above.

S&T advisory mechanism

Since Independence, a number of high-level committees or advisory mechanisms have been constituted to guide and advise the government on such S&T matters as research coordination, international collaboration and civil and defence research; to plan for scientific growth; and to monitor the implementation of S&T policies for national development. These are listed in Table 1. The members of these committees are senior policy makers, administrators and planners and eminent persons representing a cross-section of S&T fields.

In addition to these committees, S&T advisory committees (STACs) have been set up in various central socio-economic ministries, with S&T councils in the states to identify appropriate S&T plans, programmes and relevant technologies.

TABLE 1
INDIAN HIGH-LEVEL SCIENCE AND TECHNOLOGY COMMITTEES

Committee	Year of establishment
Science Advisory Committee to the Prime Minister (SAC)	1948
Scientific Advisory Committee to the Cabinet (SACC)	1956
Committee on Science and Technology (COST)	1968
National Committee on Science and Technology (NCST)	1971
Science Advisory Committee to the Cabinet (SACC) and also Cabinet Committee on Science and Technology (CCOST)	1981
Science Advisory Council to the Prime Minister (SAC to PM)	1986
National Science and Technology Council (NSTC)	1990

Higher education and S&T personnel

It was recognized, at the very dawn of Independence, that trained personnel were an essential prerequisite for carrying out S&T activities in the pursuit of economic and social development. The development of university education has been subsequently guided by the various education committees and commissions set up by the government. As a result of their work, there has been a phenomenal increase in the number of universities and professional colleges in India. Today, there are 210 universities and more than 7 500 colleges, of which roughly 6 400 offer training in general science and arts, 500 in engineering, 450 in medicine and 150 in agriculture. In addition, there are about 900 approved polytechnic institutions, 300 schools of nursing, a number of industrial training institutes and professional societies and other non-formal education and training programmes turning out middle-level skilled personnel.

Expansion in the infrastructure for S&T education has resulted in the steady growth of S&T personnel available in the country over the years. The annual enrolment in S&T disciplines in recent times has been of the order of 1.4 million, as detailed in Table 2. The average yearly output of S&T graduates is of the order of 0.2 million, and the total stock of qualified S&T personnel is estimated to be in excess of 4 million.

TABLE 2
ENROLMENT IN SCIENCE AND ENGINEERING IN HIGHER EDUCATION IN INDIA, 1992-93

Field	Male	Female	Total
Science	790 400	377 200	1 167 600
Natural science	624 000	318 600	942 600
Medical science	109 700	53 800	163 500
Agricultural science	56 700	4 800	61 500
Engineering and technology	214 900	19 200	234 100
Science and engineering, total	1 005 300	396 400	1 401 700

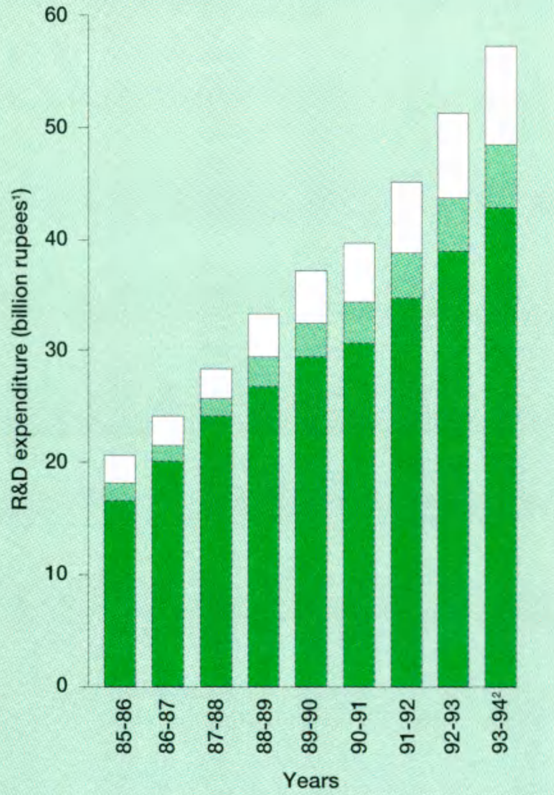
Source: University Grants Commission (latest available data).

There have been problems associated with the expansion of higher education and qualified S&T personnel. The full potential of the qualified S&T personnel is not being used for increasing organizational productivity and efficiency and for the economic development of the country. Moreover, there is unemployment, underemployment and misplaced employment, in addition to a significant number of people who are not economically active. The fact that talented scientists and technologists are emigrating to Western countries and the Middle East in search of better opportunities is a cause for concern.

It is realized that in India the interaction and coordination between the S&T system and the productive sector is rather weak. This has led to insufficient use of the scientific research conducted in universities, national laboratories, industry and elsewhere. It is recognized that the quality of higher education is not the same in all institutions as a result of falling standards and inadequate facilities.

Proposals are presently under way for the revamping of the Indian S&T education system to meet the needs of industry and the economy, and to meet the challenges of the 21st century. There is a plan to set up a university electronics communication system so that teaching institutions and national laboratories can communicate with each other and with the international community, and fax and e-mail facilities and databases are being made widely available. The All-India Council for Technical

FIGURE 2
GROWTH OF NATIONAL R&D EXPENDITURE



1. US$1 = 26 rupees (1992).
2. Estimated.

Source: *Research and Development Statistics 1992-93*, New Delhi: Department of Science and Technology.

Education (AICTE) has been given statutory responsibility for ensuring high standards in engineering and technology institutions and for the accreditation of institutions. On similar lines, the National Assessment and Accreditation Council (NAAC) was established with the following objectives: to grade higher educational institutions and their programmes; to stimulate the academic environment and quality of teaching and research; to promote innovations and reforms; and to encourage self evaluation and accountability. The brief includes curriculum design and revision; the modernization of courses in new and emerging areas; the development of new techniques in teaching and evaluation; and the evolution of support services. The new national economic policy and the consequent liberalization and globalization are adding a new dimension to industry's thinking, and should create new challenges and lead to greater exposure of students and staff to the industrial scene. Some effects are already becoming evident.

R&D resources

A national survey on resources devoted to S&T activities is undertaken biennially in India by the National Science and Technology Management Information System (NSTMIS) of the Department of Science and Technology (DST) and comprehensive reports have been published ever since 1973. These reports serve as source books and reference materials

TABLE 3
R&D EXPENDITURE AND PERSONNEL IN INDIA BY SECTOR

	R&D expenditure (million rupees)		R&D personnel as at 1 April 1992			
Sector	**1992-93**	**1993-94[1]**	**Scientists and engineers[2]**	**Auxiliary[2]**	**Administrative[2]**	**Total[2]**
National, total	51 416	57 334	95 486 (9)	98 202 (7)	99 660 (13)	293 348 (10)
Central government, total	38 911	42 724	53 389 (9)	70 028 (7)	59 634 (14)	183 051 (10)
Institutions	33 044	36 012	39 263 (10)	64 433 (7)	56 973 (14)	160 669 (10)
Public-sector industry	5 867	6 712	14 126 (6)	5 595 (7)	2 661 (11)	22 382 (7)
State governments	4 788	5 611	19 041 (9)	17 549 (6)	31 265 (10)	67 855 (8)
Private-sector, total	7 717	8 999	23 056 (9)	10 625 (12)	8 761 (18)	42 442 (11)
Private-sector industry	6 871	8 011	20 130 (6)	8 320 (4)	4 811 (11)	33 261 (6)
Private non-profit research institutes	846	988	2 926 (25)	2 305 (39)	3 950 (25)	9 181 (29)

1. Estimated.
2. Percentage share of females in brackets.

Source: *Research and Development Statistics 1992-93*, New Delhi: Department of Science and Technology.

for national and international bodies. Reports have been published for the year 1992-93, and the survey for the year 1994-95 is underway.

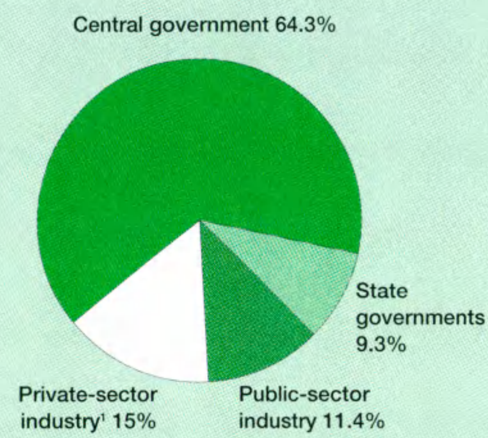
The growth of R&D expenditure in the various sectors over time may be seen in Figure 2. Data on R&D expenditure and personnel by sector for the year 1992-93 are provided in Table 3. Table 4 shows the distribution of national R&D expenditure by UNESCO-defined objectives. The percentage share of national R&D expenditure by sector during the year 1992-93 is set out in Figure 3.

TABLE 4
NATIONAL R&D EXPENDITURE IN INDIA BY OBJECTIVES, 1992-93

Objective	%
Defence	19.2
Development of agriculture, forestry and fishing	17.6
Promotion of industrial development	16.4
Space	9.6
Production, conservation and distribution of energy	7.9
Development of transport and communication	6.7
Development of health services	5.5
General advancement of knowledge	5.4
Protection of the environment	4.6
Others	7.1
Total (51.4 billion rupees)	**100.0**

Source: *Research and Development Statistics 1992-93*, New Delhi: Department of Science and Technology.

FIGURE 3
NATIONAL R&D EXPENDITURE IN INDIA, 1992-93



Total expenditure 51.4 billion rupees

1. Private-sector industry includes private non-profit research institutes.
2. US$1 = 26 rupees (1992).

Source: Department of Science and Technology, New Delhi.

Achievements

India today ranks among the few developing countries to have achieved self-sufficiency in food production, as well as making remarkable strides towards fulfilling the basic needs of health care and housing for a vast majority of its people. In the high-tech area of space research, India has successfully launched a polar satellite launch vehicle and in placing its IRS-P2 satellite into orbit has joined the select group of countries capable of launching 1 000 kg-class satellites into polar sun-synchronous orbit. India is now able to design, build and launch its own satellites. Another major achievement has been the development of indigenous supercomputers – for example the PARAM 9000 with a capacity of 2.5 gigaflop which is available in several versions. Indian scientists have been able to crystallize one of the best known natural products of neem, Azadirachtin-A, which possesses amazing attributes including the ability to act as an anti-feedant to over 200 species of insects. India, for the first time, has filed a patent for a genetically engineered gene from the mature seeds of the amaranth, a pseudo-cereal with a rich protein content; this gene can be introduced into other cereals and bring about an increase in their protein content. A large number of technologies have been developed and commercialized in the area of petrochemicals, agrochemicals, industrial catalysts, food processing, drugs and pharmaceuticals, engineering materials and equipment, and construction materials to cite a few, and many of these are marketed abroad.

International/regional collaboration

Present and future collaboration with industrialized countries can lead to the generation of indigenous know-how in many advanced technologies – such fields as microelectronics, materials synthesis, precision instrumentation, bio-engineering, coal gasification, alternative fuels, etc. Cooperation among the countries of the South Asian region would be beneficial in areas such as groundwater exploration, food processing, non-conventional (or renewable) energy, medicinal plants, low-cost housing materials, the leather industry, pesticides, information processing and documentation.

AFGHANISTAN

Afghanistan, often called the crossroads of Central Asia, has had a turbulent history and suffered many invasions. It could be regarded as one of the countries of the world least touched by developments in science and technology. It is endowed with a wide range of minerals and huge natural gas deposits. Higher education in the country is the weakest component of the education system; most of the higher education institutions established by other countries lack relevance to the socio-economic needs of the country. Inadequate educational planning, shortage of S&T personnel, heavy dependence on foreign experts, lack of opportunities for highly qualified S&T personnel and want of political will have all served to hamper the emergence of conditions for the development of S&T. The country suffers from the non-availability of capital equipment for modernization and so international, regional and bilateral cooperation is largely confined to the acquisition of the same. Another important factor keeping S&T underdeveloped in the country has been periods of internal political instability in quick succession. The country is currently in need of extensive S&T personnel to support its technology-based programme.

The National S&T Commission (NSTC) established in 1979, with members drawn from various ministries, is the body responsible for policy making and procedures relating to the coordination and popularization of S&T, and the selection and transfer of appropriate technology. The major organizations which either support or undertake research are the Academy of Sciences of Afghanistan, the Ministry of Higher Education, the Ministry of Agriculture and the Ministry of Mines. These are supported by various S&T departments, centres and institutes in different S&T disciplines. S&T statistics for the country are not available, but it is generally known that the scale of R&D is low.

BANGLADESH

Bangladesh is in the process of giving formal recognition to the role of science and technology in the development effort.

Bangladesh announced its first National Science and Technology Policy in 1983, but this could not be implemented due to lack of support. This prompted the government to announce a second Policy in 1986. The government established the National Committee on Science and Technology (NCST), with the Prime Minister as its chairperson, whose terms of reference were to recommend national S&T policies and priorities, give approval to research plans and programmes, and suggest measures for the coordination of R&D activities and any related matters. There is also an Executive Committee of NCST (ECNCST) headed by the Minister-in-charge of the Ministry of

Science and Technology (MOST) to oversee the implementation of the directives and decisions of the NCST.

There are no private or in-house research institutions in Bangladesh. The research organizations include the Bangladesh Atomic Energy Commission (BAEC) and the Bangladesh Council of Scientific and Industrial Research (BCSIR), universities, testing and research laboratories, medical research-cum-hospital centres and scientific support service organizations grouped under 12 ministries.

Research activities in the universities are very limited. About 95% of PhD holders in science and engineering received their training abroad. Local PhDs are few, though universities claim to have introduced PhD programmes. Bangladesh is far from being able to achieve real national S&T competence. Meagre research funding, inadequate laboratory facilities, poor linkage with industries and a lack of pilot plant studies of research results have all contributed to the low level of R&D in the country.

BHUTAN

Bhutan's efforts to develop a modern economy are of recent date. Bhutan has been exemplary in its concern for its own ecology and, as a result, has been able to retain its natural environment largely intact. However, pressures are now building up rapidly, due to population growth and increased livestock populations, and serious harm to the environment is threatened. The country's overall strategy aims at accelerated development of industry, mining and power based on the large hydroelectric potential, and its mineral and forest resources. Despite the objectives of the Sixth Plan relating to economic self reliance, human resource development, etc., the country is facing a very serious shortage of skilled and technical personnel, a lack of institutional infrastructure and a dearth of trained teachers. Bhutan is dependent on foreign experts and expatriates; except for one or two agriculture-related research institutions, there exists hardly any infrastructure for S&T, nor has the country an S&T policy or policy-making body. There is no reliable data collection mechanism and so the statistical information on the S&T base is weak.

MONGOLIA

Mongolia became a full member of COMECON in 1962 and remained so until the collapse of the organization in 1990. Competition between the country's two large neighbours, China and the Soviet Union, was a spur to modernization, and promoted the development of industry, infrastructure and urbanization. Education and training in Mongolia continue to suffer from shortages of buildings, equipment and teachers. The system now faces the added problem of reorienting and training the young in a market-based economy.

Since mid-1993, a new law on foreign investment has come into force, intended to promote heavy industry and exports. However, in virtually all areas of the manufacturing sector, Mongolia continues to be largely reliant upon imports. Mongolian engineers have usually played a secondary role in their establishments, and there has been little opportunity for Mongolian technicians to develop the requisite skills. The government has a technology modernization programme, recognizing the need completely to reorient the technical and vocational training system to meet new requirements, and fresh skill development programmes are being created by the Ministries of Labour and Education.

MYANMAR

According to information published in 1976, Myanmar had a Research Policy Direction Board, a committee of ministers set up in 1965, in charge of the overall planning and coordination of S&T. Although it performs no operational work itself, the

Board is assisted in its work by an advisory body and a Research and Development Co-ordination Committee, made up of members with specialized knowledge in science, engineering and social sciences. Information published in 1986 refers to Myanmar as having established a State S&T Commission responsible for S&T policy. The Research Society of Myanmar, set up in 1910, promotes cultural and scientific studies and research. The Applied Research Institute, one of the main research bodies, along with three centres, viz. the Technical Information Centre, the Instruments Centre and the Atomic Energy Centre, is concerned with industrial and technological research. Myanmar has three universities which carry out scientific research. In addition, there are ministry-run national research institutes, such as the Agricultural Research Institute and the Medical Research Institute, which conduct research in their respective domains.

NEPAL

Teaching of science at the postgraduate level started in Nepal in 1965 following the establishment of the first university in 1959. A new national education system was introduced in 1971. Laboratories and research institutes established between 1960 and 1973 included the important Research Center for Applied S&T (RECAST) at Tribhuvan University. Nepal set up the national Council for S&T in 1976 and the Royal Nepal Academy of S&T (RONAST) in 1982. RONAST is the equivalent of a national technology authority, and its functions and duties are to formulate and implement S&T policy and programmes; coordinate and conduct S&T research; establish national laboratories; develop an S&T information system; and popularize S&T.

Nepal's R&D expenditure expressed as a percentage of GDP is about 0.13%, one of the lowest in the South Asian region. Total R&D budget allocation, comprising public, private and foreign aid, was 2.34 billion rupees in 1984-85. The stock of S&T personnel in 1990 totalled 34 000, of which just over half were engineers. The country is said to have a 20% shortage of scientists and engineers.

PAKISTAN

The importance of S&T has been realized in Pakistan in recent years and given due weight by policy makers and planners. The Ministry of Science and Technology (MOST), the focal agency in the federal government for S&T development, formulated a National Science and Technology Policy which was approved in March 1984. An S&T Action Plan for the implementation of this policy was approved in 1985. The National S&T Policy aims to lay a sound foundation for building up an efficient S&T system in order to reduce dependence on imported technologies and to ensure that the S&T system is directed towards the achievement of national goals. It addresses itself to the organization and structure of S&T; university research; technology development; S&T personnel; promotion of S&T in society; international liaison; and financing of the S&T programme.

Pakistan prepared its Second Perspective Plan (1988-2003) in the context of domestic and international events, technological innovations and the information explosion. The Seventh Five-Year Plan (1988-93) emphasized the consolidation of existing R&D institutions to respond adequately to national development by integrating S&T with national development plans, the expansion of personnel development programmes, etc.

In Pakistan, the major obstacle to utilizing advances in S&T in the process of development is not the lack of adequate funds or sophisticated equipment and machinery, it is the sub-critical size of qualified and trained personnel in universities, R&D institutions and the industrial and agricultural sectors. A Human Resource Development Programme was accordingly launched by the MOST in 1985 for advanced-level training in new and emerging technologies, to upgrade the S&T

TABLE 5
SECTORAL ALLOCATIONS FOR S&T BY THE PAKISTAN FEDERAL GOVERNMENT, 1988-93

Sector	Total outlay (million rupees)	S&T allocation (million rupees)
Agriculture	9 511	1 439
Industry	7 278	804
Minerals	5 232	260
Water	19 224	124
Energy		
Power	89 347	757
Fuels	34 100	–
Transport and communications	52 074	294
Physical planning and housing	2 640	20
Education, science and technology	11 153	3 260
Health	3 073	84
Social, cultural and population welfare programme	14 665	–
Federal total	**248 297**	**7 042**

Source: Asian and Pacific Centre for the Transfer of Technology (APCTT, 1991).

potential of the country and to create a critical mass of highly qualified personnel. To promote research at the universities, it is proposed to revive a Board of Advanced Studies and Research (BASR) at each university and to strengthen libraries, documentation and laboratory facilities, advanced training, separate R&D funding, etc.

The Seventh Five-Year Plan allocated 7.04 billion rupees (5.8 billion rupees in the Sixth Plan) for S&T development, distributed as shown in Table 5. R&D expenditure as a percentage of GNP during 1987-88 was 0.42%.

The National Technology Policy (NTP) and Technology Development Action Plan (TDAP) were announced in November 1993. The NTP aims to optimize technology-based development, building on the existing science base, whilst the Action Plan underlines specific policy actions and projects to meet the aims of the NTP.

The S&T effort in Pakistan is presently organized in the following manner. The principal body concerned with policy making, planning and coordination of S&T is the Ministry of Science and Technology linked with two important autonomous organizations, the Pakistan Council of Science and Technology (PCST) and the Pakistan Science Foundation (PSF). The major functions of the PCST are: to advise the government on science policy and promotion of national scientific effort; to review the work of research councils; and to ensure linkage of science with national development plans. The PSF is primarily a financing agency for the promotion of basic and fundamental research.

S&T research work is largely carried out in:

- autonomous or semi-autonomous organizations administratively linked with the federal ministries or the Prime Minister's Secretariat;
- S&T institutes and field stations under the federal and provincial governments;
- small S&T units in private- and public-sector industry.

In 1990 Pakistan had almost 16 000 personnel engaged in R&D, of which 6 626 were scientists or engineers. The breakdown of the latter figure by discipline was: 2 558 natural sciences, 2 409 agriculture, 1 277 engineering, 315 medicine and 67 social sciences.

SRI LANKA

Sri Lanka enjoys an 89% adult literacy rate, yet it is only in recent years that explicit commitment to education has been extended to the recognition of S&T as a key factor in development. The Natural Resources, Energy and Science Authority (NARESA), constituted in 1981, was the legal successor to the National Science Council of Sri Lanka (NSC) set up in 1968, and can be considered as the national technology authority which advises the Minister on science policy.

NARESA is one of the main research funding organizations for the scientific disciplines in Sri Lanka. It enjoys a stronger position than in the past, as it is now under a cabinet ministry, namely the Ministry of Science, Technology and Human Resource Development (MSTHRD).

The national S&T policy of Sri Lanka broadly consists of four aspects: structuring of inputs to R&D in relation to availability and future needs, determining national research priorities, prioritizing industrial competitiveness and ensuring medium- and long-term research in frontier areas. Science policy has been recently undergoing revision in Sri Lanka.

There is no central organization to advise or monitor technology transfer mechanisms, but the National Engineering Research and Development Centre (NERDC) and the Ceylon Institute of Scientific and Industrial Research (CISIR) facilitate such transfers.

TABLE 6
SELECTED SOCIO-ECONOMIC DATA FOR COUNTRIES OF SOUTH ASIA

		Afghanistan	Bangladesh	Bhutan	India	Mongolia	Myanmar	Nepal	Pakistan	Sri Lanka
Mid-year population 1992 (millions)		19.1	119.3	1.6	870.0	2.3	43.7	20.6	119.1	17.4
GDP at current prices (million US$) (1992)		11 495	23 783	238	242 269	966	37 749	2 763	41 904	8 769
Adult literacy rate	Total	32	37	41	50[1]	na	82	37	36	89
(as % of age 15 +)	Male	48	49	55	64[1]	na	90	39	49	94
(1992)	Female	15	23	26	35[1]	na	72	14	22	85
Expenditure on education as % of GNP[2]		4 (1988)	2.3 (1992)	3.4 (1988)	3.7 (1992)	8.5 (1991)	2.4 (1989)	2.0 (1991)	2.7 (1991)	3.3 (1993)
Enrolment in higher education[2]		24 333 (1990)	434 309 (1990)	422 (1986)	4 804 500 (1992-93)	28 209 (1991)	260 200 (1991-93)	110 339 (1991)	721 600 (1992-93)	61 628 (1988)

na = not available.
1. As percentage of age 7+ for India.
2. Year of reference of data is shown in brackets.

Source: *UNESCO Statistical Yearbook*, 1994; *Human Development Report*, 1994; *The World of Learning*, 1994; Association of Indian Universities for Indian data; UNCTAD, *The Least Developed Countries Report 1993-94*; *World Bank Country Study for Bhutan* (1989); *World Development Report, 1994.*

The universities have very little money for research. NARESA provides research grants, as well as negotiating foreign grants for individual universities and administering grants for research institutes in other ministries.

Owing to financial regulations and the country's budgetary constraints, only 0.13% of GDP was devoted to R&D in 1990, a drop from the 0.18-0.19% level recorded throughout the 1980s. Agricultural institutes are given the highest priority for research. About 11% of total R&D expenditure is from foreign funding.

TABLE 7
S&T ENROLMENT IN HIGHER EDUCATION IN SOUTH ASIA

Country[1]		Natural science	Medical science	Agricultural science	Science total	Engineering[2] total	Science and engineering[2] total
Afghanistan (1990)	Total	1 237	655	1 256	3 148	504	3 652
	Female	666	286	307	1 259	183	1 442
Bangladesh (1990)	Total	83 026	7 641	4 175	94 842	6 126	100 968
	Female	13 791	2 087	291	16 169	300	16 469
Bhutan	Total	na	na	na	na	na	na
	Female	na	na	na	na	na	na
India (1992-93)	Total	942 600	163 500	61 500	1 167 600	234 100	1 401 700
	Female	318 600	53 800	4 800	377 200	19 200	396 400
Mongolia (1986)	Total	1 102	5 899	5 788	12 789	12 803	25 592
	Female	715	5 190	2 744	8 649	5 465	14 114
Myanmar	Total	na	na	na	na	na	na
	Female	na	na	na	na	na	na
Nepal (1991)	Total	12 113	1 777	1 175	15 065	2 268	17 333
	Female	1 565	921	111	2 597	196	2 793
Pakistan (1989)	Total	28 663	48 482	17 380	94 525	66 473	160 998
	Female	6 523	16 360	253	23 136	1 453	24 589
Sri Lanka (1991)	Total	8 594	4 787	2 095	15 476	6 853	22 329
	Female	2 239	1 867	878	4 984	1 162	6 146

na = not available.
1. Year of reference of data in brackets.
2. Engineering includes technology.

Sources: *UNESCO Statistical Yearbook*, 1994; University Grants Commission for India.

TABLE 8
INSTITUTIONS IN SOUTH ASIA BY TYPE

Country	Academies	Learned societies	Research institutes	Universities	Colleges	Libraries/ archives	Museums
Afghanistan	1	2	2	5	23	6	7
Bangladesh	1	15	11	7	163	11	3
Bhutan	1[1]	–	–	1	7	2	1
India	12	400	2 545	210	7 513	885[2]	50
Mongolia	1	–	67	4	6	4	9
Myanmar	–	7	9	3	36	25	7
Nepal	2	5	–	3	–	9	1
Pakistan	3	49	54	23	774	51	13
Sri Lanka	1	23	23	10	8	15	10

– = not available/nil.
1. Special Commission.
2. Libraries covered under National Union Catalogue of Scientific Institutes (850 libraries and 35 archives).

Sources: *The World of Learning*, 1994. For Indian data: *S&T Pocket Data Book*, 1993; Indian National Scientific Documentation Centre; Association of Indian Universities.

CONCLUSIONS

The scientific communities in the South Asian region share a number of problems and difficulties, the intensity of which varies from country to country. The facilities for research are generally inadequate, and scientific research has a relatively low social status and poor income standards in comparison with other professions. There is a shortage of qualified and trained personnel yet somewhat paradoxically such educated personnel as exist are often underutilized, and there is a tendency for authorities to devalue their own S&T personnel by relying excessively on 'foreign experts'. Individual scientists suffer from lack of training in techniques and lack of research freedom. There is little wonder, then, that brain-drain is an over-arching problem in countries of the region. Politically, there is frequently a lack of commitment towards science and technology, and the result is a deficiency in S&T planning and its coordination with other sectors. Private sector industrial R&D is virtually non-existent in South Asia, and due to policy concentration on R&D as an input activity, technology innovation is accorded only limited resources and effort.

Tables 6 to 9 present the latest available data on socio-economic and S&T features of the countries discussed in this chapter. Lack of information-gathering structures in certain states mean that the quality and quantity of data available are not always satisfactory.

Areas of research relevant to the region include the following: groundwater exploration; food processing; non-conventional (or renewable) energy sources; low-cost housing materials; medicinal plants; biotechnology; ecology, environment and pollution research; remote sensing; information networking, processing and documentation.

There is clearly need for regional cooperation through which experience might be shared on

TABLE 9
PERSONNEL ENGAGED IN R&D IN SOUTH ASIA

			Scientists and engineers		Technicians	
Country[1]	**Year**	**Total (FTE**[1]**)**	**Total**	**Female**	**Total**	**Female**
India	1992	193 688	95 486	8 490	98 202	7 096
Myanmar	1975	2 220	1 720	na	500	na
Nepal	1980	409	334	na	75	na
Pakistan	1990	15 940	6 626	464	9 314	na
Sri Lanka	1985	3 483	2 790	667	693	188

Note: No data available for Afghanistan, Bangladesh, Bhutan or Mongolia.
na = not available.
1. FTE = full time equivalent.

Sources: *UNESCO Statistical Yearbook*, 1994; *Research and Development Statistics 1992-93*, New Delhi: Department of Science and Technology.

technological development and industrialization. Some specific areas would be: the coordination of long-term strategic research areas; the establishment of computer networks and information exchanges; the shared use of higher S&T education and training facilities, and teaching expertise; and the formulation of a regional policy of bilateral and multilateral cooperation.

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Iran

CYRUS YEGANEH

Iranian culture and civilization both before and during the Islamic era have had a great affinity for science, technology and development while simultaneously adhering to high levels of spirituality and morality. A very strong foundation for scientific and technological advances was interwoven with Iranian civilization, especially of the Islamic era, during which towering figures such as Avicenna, Razes, Khwarazmi, Khayyam, Suhrewardi and Rumi set Persia apart from other countries in the contemporary world.

During the centuries that followed, the Holy Prophet's dictum, 'Seek science even if [it is as far away as] in China', precluded any contradiction between religion and science. The Islamic culture and civilization of Iran thus continued to set a high value on scientific learning, and individuals demonstrated high levels of aptitude and achievement in science. However, the present situation is far from satisfactory, since the institutions, structures and social organization that are the prerequisites of advanced science have been absent in Iranian society for the past few centuries. Whilst the 20th century has seen a gradual rebuilding towards modern structures and forms of organization, the process has been marred by two world wars, the intervention of strong external powers, internecine violence and social upheaval. Today the economic forces that elsewhere in the world have driven science and technology are taking shape in Iran, but there is a long way to go before society's full potential in this area is realized. Until such a time, the 'brain drain' is just one result of this situation.

Despite rich and varied natural resources and a population with generally favourable attitudes towards science, there seems to be a lack of interest in science and research on the part of most enterprises. The relative weakness of the economy, resulting primarily from excessive dependence on oil exports and the predominant mind-set in the country, is the major structural obstacle to the development of science and technology (S&T) on a scale comparable with the industrialized countries. There are very few individuals, even highly educated ones, who have a realistic view of the nation's annual oil income. This stands at an impressive-sounding US$14 billion, but in practice it represents a rather meagre per capita income of US$150 per annum; the total figure is the equivalent of the gross sales of a medium-size corporation in many other countries – and far less than that of such major corporations as Sony, Walmart or Gulf, whose annual sales are US$33 billion, 44 billion and 150 billion, respectively.

The total value of annual imports is currently US$20 billion, and non-oil exports are US$4.4 billion. Only US$1.1 billion returns to the domestic economy; the remainder constitutes flight capital. The foreign debt currently stands at US$6 billion. Non-oil exported goods include carpets, pistachios, iron and steel, chemicals, copper and hides. In the face of a per capita income of US$1 000, the Iranian government has heavily subsidized goods and services; US$3.5 billion is spent on importing 39 essential goods ranging from cooking oil to rice and sugar (requiring US$560 million, 308 million and 270 million, respectively).

There is no major industry that is not government-owned, resulting in one of the most heavily centralized economies in the world. Consequently, the organization and management of most enterprises are not up to Western levels; work motivation and discipline are similarly weak. The economy is characterized by scarcity and monopoly, with low quality of goods and services. There is thus no inherent incentive for R&D on the part of most enterprises. The result is low productivity, and the vicious cycle of weak purchasing power, low quality and quantity of production, dependence on government subsidies for imported essential items and lack of inducement for motivation to achieve.

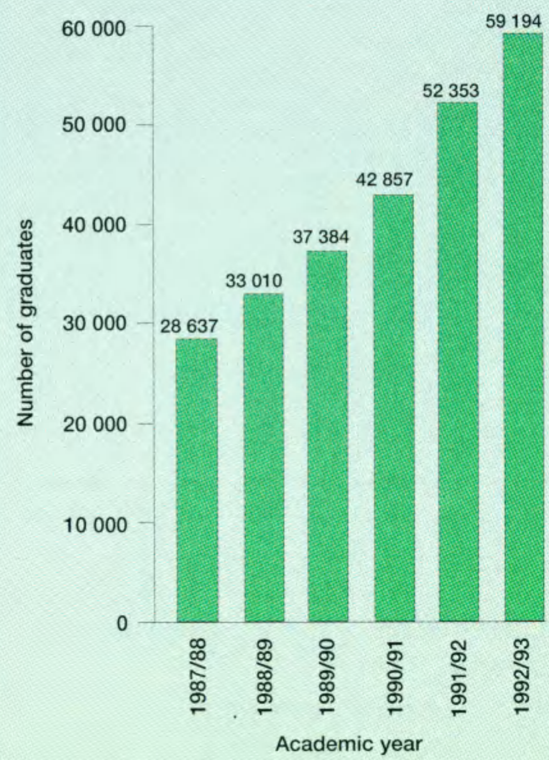
GOVERNMENT SCIENCE POLICY

There are a total of 112 research institutes active in Iran, which are run by various ministries and agencies.

The dominant institutions of scientific enterprise in Iran are as follows:

- The Ministry of Culture and Higher Education (MCHE), Vice Ministry for Research, is responsible for the leadership and overall coordination of research at 40 universities and 14 associated research institutions. The Ministry of Health, Treatment and Medical Education runs 26 medical universities.
- The Ministry of Culture and Higher Education, Vice Ministry for Technology, was created very recently and is responsible for the dominant research institution, the Iranian Organization for Research and Technology (IROST), where mostly applied research and experimental development up to semi-industrial production is carried out in eight departments, including biotechnology and mechanical engineering.
- The National Research Council is the dominant body for overseeing research policy. It operates under the President's office and consists of seven commissions: industry, agriculture, water, energy, science, social and human science, and medicine, each coordinating research policy in the related ministry research departments, universities and research institutes.

FIGURE 1
TERTIARY-LEVEL GRADUATES IN IRAN, 1987-1993



Source: Ministry of Culture and Higher Education, 1994.

During the second (i.e. current) five-year economic, social and cultural development plan, a number of measures have been adopted by the National Research Council, including support for the research sector in the short- and mid-term, inducement for public and private investment in research, support for public and private research centres, the creation of R&D units in industry and an improvement in the utilization of research results. Efforts are being made towards creating regional and international research centres in Iran.

During the first five-year plan the policy was for expansion of universities, enabling each province to have at least one institution. As part of the second plan priority is to be given to the qualitative improvement of higher education, and MCHE is mandated to hire 10 000 new university instructors and assistant professors. Universities are beginning to move towards research contracts with government and private enterprises, although the movement is slow.

HUMAN RESOURCES IN SCIENCE

Statistics on graduates of tertiary-level education have shown a steady rise during the past few years

TABLE 1
TERTIARY-LEVEL GRADUATES IN IRAN, 1992/93

Field	Graduates		
	Men	Women	Total
Natural sciences	4 213	2 342	6 555
Agriculture	3 029	139	3 168
Engineering	12 597	438	13 035
Medicine	7 570	9 176	16 746
Social sciences, humanities	12 517	6 053	18 570
Art	656	464	1 120
Totals	40 582	18 612	59 194

Source: Ministry of Culture and Higher Education, 1994.

(Figure 1). The breakdown by discipline for the academic year 1992/93 is presented in Table 1. Noteworthy are the very low numbers of women graduates in engineering and agriculture; the high figures with regard to medicine may be partly explained by the inclusion of nursing and paramedical subjects.

During the academic year 1993/94 there were 436 564 students enrolled at 153 institutions of higher education attached to 26 ministries and other agencies, including the MCHE. About 500 000 more were enrolled at the privately funded Open University.

The number of personnel engaged in research and development in Iran in 1993 is shown in Table 2. It is significant that of the total 39 311 R&D workers (excluding auxiliary workers), 25 188 are engaged in universities and 14 123 in the non-university sphere, compared with such countries as Germany where 296 510 scientific workers are engaged in the productive sector, 69 667 in the higher education sector and 60 269 in the general service sector. Comparable figures for Belgium are 25 515, 11 846 and 1 412; and for Japan, 563 018, 264 055 and 82 978 (UNESCO, 1994*a*). The separation between the productive and higher education sectors in Iran is thus very pronounced.

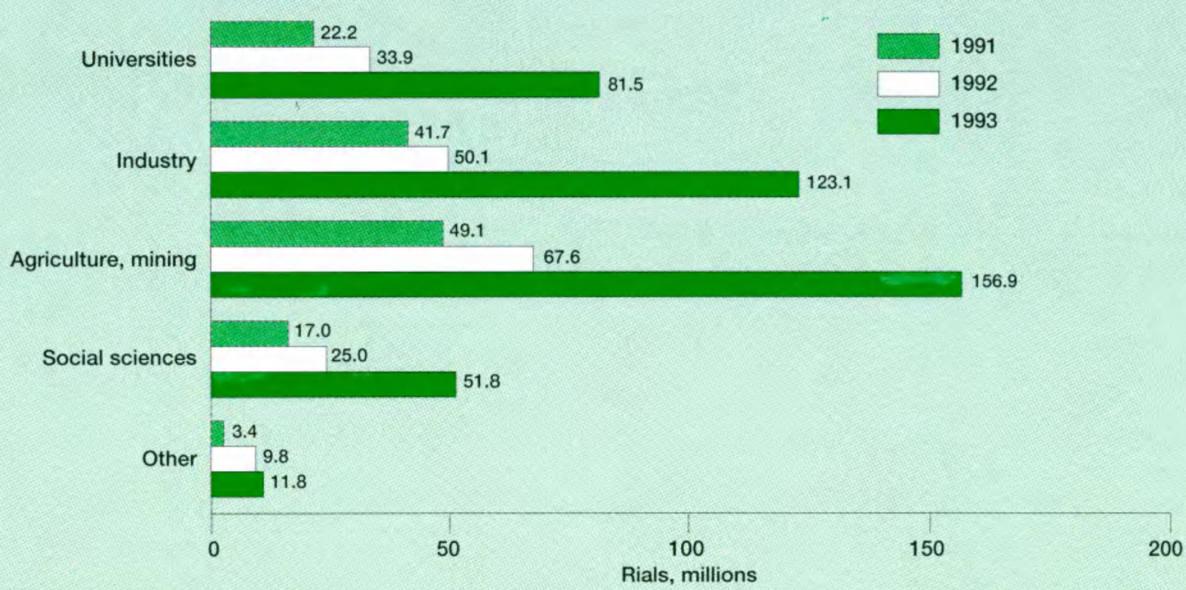
The total number of engineers, scientists and research assistants per million population stands at

TABLE 2
PERSONNEL ENGAGED IN R&D IN IRAN, 1993

	Government sector		Non-government sector		Total		
	Men	Women	Men	Women	Men	Women	Total
Engineers and scientists	16 522	2 548	2 109	571	18 631	3 119	21 750
Research assistants	5 226	2 268	240	153	5 466	2 421	7 887
Technicians	6 833	2 579	194	68	7 027	2 647	9 674
Auxiliary workers	3 291	1 229	149	113	3 440	1 342	4 782
Total	31 872	8 624	2 692	905	34 564	9 529	44 093

Source: National Research Council, 1995.

FIGURE 2
IRAN R&D BUDGETS BY PROGRAMME



Source: National Research Council, 1995.

493 for 1993, which is higher than the figures for Latin America and the Caribbean (364) and the Arab States (363) (UNESCO, 1994*a*).

R&D EXPENDITURE

Figure 2 shows R&D budgets in local currency. The current exchange rate is Rials 1 750 to US$1. The gross expenditure on R&D (GERD) stood at 0.40% of gross domestic expenditure (GDP) in Iran in 1992, whilst in 1993 it had risen to 0.53%.

FUTURE PROSPECTS

The country and government are basically recovering from the war with Iraq which caused destruction estimated at US$1 000 billion. There is much reconstruction to be completed, and a good deal that has already been done. One outcome of the war has been a movement towards self-reliance, especially in the industries linked with defence – electronics, metallurgy and engineering – but also in consumer goods and such heavy industry as petrochemicals.

Government building programmes in infrastructure (highways, dams, electrification and natural gas pipelines to remote villages) generate movement in the science and technology fields. The gradual liberalization from top-heavy government involvement in manufacturing, services and distribution is well under way and needs to go further before its effects are felt throughout the economy to the point where a motivating force for R&D and S&T is set in motion. All government policy which facilitates this movement is to be welcomed. There is great need for mechanisms to mobilize the capital that is lying dormant and create opportunities for manufacturing and distribution of goods – without direct government control and involvement – and to engender self-confidence, self-reliance and entrepreneurship among the population. The creation and strengthening of legal guarantees for efforts in the economic field are vital for future prosperity.

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South-East Asia and the Pacific Rim[1]

STEPHEN HILL, TIM TURPIN AND HEATHER SPENCE

Thirty years ago, in 1965, UNESCO sponsored the first science policy and management conference in Asia. Held in Australia under the auspices of Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO), the conference drew together a number of the key players who were to prove influential in the establishment of the presence of science in Asia. For example, amongst those present were Abdul Rahman, one of the architects of science planning in India, Cyril Ponnamperuma, leader of Sri Lanka's basic research initiatives, and Hyung-sup Choi, founder of the Korean Applied Institute for Science and Technology (KAIST) and architect of the Republic of Korea's subsequent science and technology policies. Together, these people represented the tensions between the different views of science that were played out in subsequent Asian development strategies – from comprehensive government planned science, to more *laissez-faire* public sector 'science-push' approaches, to the reverse engineering industrial demand-driven approach that characterized the Republic of Korea's development. At the time of the conference Japan was in the early stages of developing a quality-led technological strategy, while Korea was still at an early stage in building the infrastructure that was basic to economic recovery following the Korean War and earlier Japanese occupation. China was a closed country enmeshed in its 'Great Leap Forward' policies to proletarianize industrial technology and, apart from largely British-inspired models of research organization with a primary focus on agriculture, little research existed at all through South-East Asia. Australia and New Zealand, also heirs to a colonial-based public sector research model, had high-quality research establishments but little drive by these establishments in industrial development (Hill, 1992). Meanwhile, South-East Asia comprised many of Asia's poorest economies. With the exception of Singapore, manufacturing accounted for less than one-quarter of gross domestic product (GDP), and less than 6% of exports (East Asia Analytical Unit, 1992: 14).

In the mid-1990s, the economic face of Asia has changed dramatically and a strong commitment to science and technology has been a key driving force. Asia, as a regional entity, now has the economic and technological potential to play a dominant role in the global economy of the 2000s. However, the observer must be aware that behind the extraordinary economic miracles demonstrated by Japan, the Republic of Korea, Chinese Taipei and the variously described 'Asian Tigers', or 'Dynamic Asian Economies' as OECD calls them, there is not just one story about Asia, but a complex web of different science and technology (S&T) stories, each reflecting differences in national culture, history and current development status.

Consequently, in the present account of science and technology in the east and south-east part of the Asian region – the Pacific Rim – we will seek to show something of the drives and constraints that characterize the region, but at the same time present at

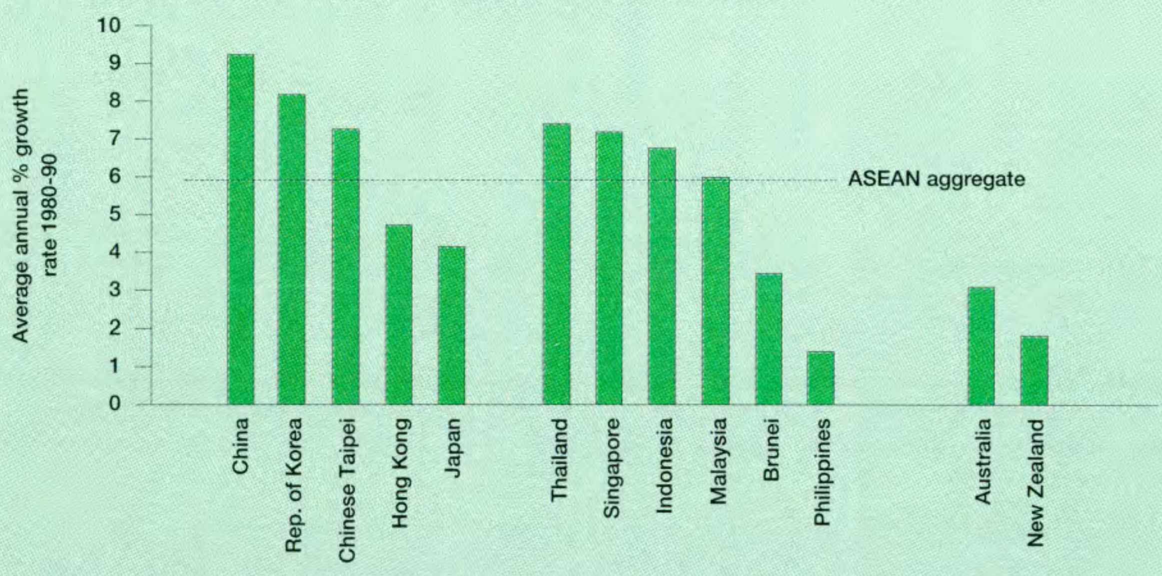
1. The present chapter was commissioned to focus on nations of East Asia, South-East Asia and Australasia. The People's Republic of China has, however, been referred to only in passing, where its presence has a significant impact on other national strategies, because China is the subject of a separate chapter. South Asia has been excluded for a similar reason. To allow the chapter to be manageable, Indo-Chinese countries have been excluded, although there are significant developments now occurring in Viet Nam. Within the East and South-East region of Asia there are then two fairly different groups of countries, the economically driving countries and areas of Japan, Republic of Korea, Chinese Taipei, Singapore and, more recently, the People's Republic of China, and the countries now grouped under ASEAN: Brunei Darussalam, Indonesia, Malaysia, the Philippines, Thailand (as well as Singapore and, recently, Viet Nam). The Australasian countries of Australia and New Zealand are included also for comparison, since over the last decade these have started to forge significantly stronger relationships with the rest of Asia. This is quite a mixed grouping of economies. The chapter therefore seeks only to present an overall picture of what is happening with science and technology across this crescent of Asia, identifying where appropriate the main variations by economic status of country and national situation. Although the description is not entirely accurate, for the sake of brevity the focus countries have been referred to as a collectivity in the present essay as the 'Pacific Rim'. In the space available, the chapter must be seen as something of a sketch of main features rather than a fully comprehensive account.

least a glimpse of the diversity that is also a key feature of Asia on the edge of the millennium.[2]

THE ECONOMIC AND REGIONAL CONTEXT

The annual real gross national product (GNP) growth of countries and economies in North-East Asia (excluding Japan) – the Republic of Korea, Chinese Taipei and the People's Republic of China – averaged between 7.3% and 9.3% over the last decade, with growth in some regions of southern China exceeding 30% per annum. Japan, the most dominant economy in the region – constituting 69% of the overall GDP of all East and South-East Asia – grew at 4.2% per annum over this same period, whilst the level of growth amongst the Association of South East Asian Nations (ASEAN) countries was also high (Figure 1). Singapore, Malaysia, Indonesia, Thailand, the Philippines and Brunei Darussalam as a group averaged 5.8% growth over the last decade. These levels of economic growth

FIGURE 1
ECONOMIC GROWTH LEVELS ACROSS SELECTED PACIFIC RIM COUNTRIES



Source: IMF (International Monetary Fund) (1992) *International Financial Statistics*, Washington, DC: IMF.

2. We would also add a caution, however. S&T data and indicators have been formed for OECD countries over two decades now. However, in Asia, such methodological rigour and consistency is less widespread. STEPAN, the UNESCO-based Science and Technology Policy Asian Network, PECC, the Pacific Economic Cooperation Council and others, have been working with individual nations and across the region on S&T information systems, but no consistent sources of data fully comparable with OECD data are yet available. The current report is therefore based on a variety of sources, including individual country collections. The most generally cited collection in the literature is that published by the US National Science Foundation in 1993 (NSF, 1993). This provides source material for most of OECD's subsequent data on Asia (OECD, 1994), for numerous reports and even part of Indonesia's own data – compiled with assistance from the USA (BPPT, 1993). However, the NSF data only refer to a small number of Asian economies and the original sources are at times not always accurate or up to date. Within the scope of the present chapter it was not always possible to test or amend these figures. UNESCO *Statistical Yearbook* data (UNESCO, 1993) are developed without access to independent methodological scrutiny of national accounts and often must depend on a country's very limited capability to conduct adequate surveys in the first place. These data are therefore likely to include significant gaps, particularly with time series, and may not always be as comparable as the tables appear. The reader therefore should exercise some caution in accepting the authority of data that, already several steps removed from original sources (such as is the case for OECD data), may be inaccurate. On the other hand, these data are the best currently available. The main published sources that are of use in analysing S&T data from the region this report addresses are outlined in References and further reading at the end of the text.

TABLE 1
ECONOMIC GROWTH LEVELS ACROSS SELECTED PACIFIC RIM COUNTRIES AND AREAS

Country/area	GDP (US$ billion at current prices)[1] 1990	Average annual % growth rate[2] 1980-90
China[3]	369.75	9.28
Hong Kong[4]	81.79	4.70
Japan	2 940.36	4.20
Rep. of Korea	244.04	8.29
Chinese Taipei	180.65	7.30
Brunei	5.10	3.50
Indonesia	107.29	6.76
Malaysia	42.37	5.82
Philippines	44.20	1.45
Singapore	35.13	7.36
Thailand	80.17	7.52
ASEAN: aggregate	314.26	5.83
Australia	294.61	3.15
New Zealand	44.03	1.85

1. Figures for GDP levels and current exchange rates for conversion from domestic currency to US$ are derived from IMF (1992). Exchange rates used depended on the economy, but were either average market rate for 1990 or the official rate for the same year.
2. Average rates of growth of GDP over the 1980s were calculated for each country by averaging from yearly figures published in IMF (1992).
3. GDP figures for China were not available from the IMF source. As GNP figures in the publication were based on a similar database to that for GDP for other countries, this figure was used rather than GDP derived from an alternative source.
4. No figures were available from the IMF source for Hong Kong, Brunei or Chinese Taipei. Growth figures from 1990 were used, based on published statistics in *Asia Week*, September 1992.

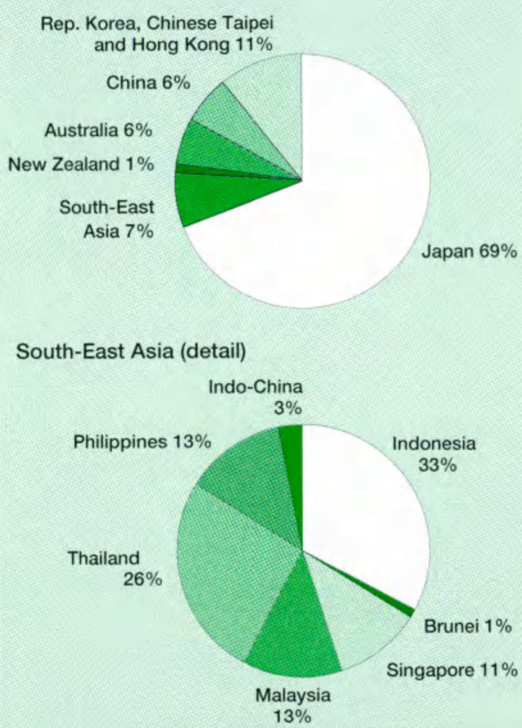
Source: IMF (International Monetary Fund) (1992) *International Financial Statistics*, Washington, DC: IMF.

stand in distinct contrast to the average OECD growth ratio for the same period of around 2.7%.

Growth represents a transformation in economic structure as well. Across all the ASEAN countries, manufacturing contributed well over one-third of GDP and over 40% of exports; standards of living improved enormously, with average life expectancy rising from 49 years in 1965 to 63 years in 1991. Singapore, according to the 1994 World Competitiveness Report, was rated the second most competitive economy in the world, trailing only the USA (Yeo, 1995: 24.2). The emerging force of Asia is demonstrated in the observation made by the *Far East Economic Review* in 1991 that Eastern Asia has now reached a 'critical mass', having achieved a combined GNP of US$1 trillion, and a larger increase in goods and services than North America and the European Community combined (Holloway *et al.*, 1991). Consequently, in spite of an overall contraction of world trade, GATT figures for 1993 indicate that the Asian region continues to increase its share in world trade, with the volume of Asian exports rising by 6% and imports rising by 10.5%.

Asia is, however, an increasingly inward-looking market. Following a wave of Japanese direct investment in the region, there is a massive increase in the demand for capital goods through Eastern Asia. Exports from the Republic of Korea to within Asia rose by two-thirds to US$5.1 billion in the two years to 1990; Asia has surpassed North America as Japan's largest market. And indeed, behind the most visible economic relations, the more rapidly developing countries of Asia have some of the strongest levels of growth in their exports to Japan. Indonesia's exports to Japan of machinery and transport equipment, and miscellaneous manufactured goods, are currently rising at an astounding 325% and 153% per annum respectively. China's Japan-oriented machinery and transport equipment exports are expanding by 115% and Thailand's miscellaneous manufactured goods exported to Japan by 116% per annum. The United

FIGURE 2
SHARE OF REGIONAL GDP BY PACIFIC RIM COUNTRY OR AREA, 1991



Notes: Indo-China refers to Cambodia, PDR Laos and Viet Nam. Data for Brunei and PDR Laos refer to 1990. Data for Indonesia and Cambodia are estimates.

Sources: *Australia's Business Challenge, South-East Asia in the 1990s*: 13, Fig. 1.1; Asian Development Bank (1992) *Asian Development Outlook*, Manilla; The Economist Intelligence Unit, *Global Forecasting Unit Quarterly Forecasts* (various countries, various quarters); International Monetary Fund (1992) *Direction of Trade*; Bank Negara (1992) *Economic Report*, Malysia.

Nations Conference on Trade and Development (UNCTAD), observed in 1990 the development of an informal Pacific Rim trading network based on Japan (UNCTAD, 1990). Since that time APEC, the Asia Pacific Economic Cooperation forum, has started to impact on strengthening the linkages within this trading region.

Australia, previously oriented in economic trade strategies towards North America and Europe, is now also becoming increasingly integrated both politically and economically into this Asian economy. During the 10 years to 1992, Australian exports to ASEAN members, for example, grew at a trend rate of 19%, significantly outstripping the 11% rate of growth in overall exports. Meanwhile, in both imports and exports, elaborately transformed manufacturing has taken over an increasing proportion of overall trade between Australia and ASEAN, i.e. from 23% to 36% of imports, and from 21% to 23% of exports over the last five years. Australia is not a minor player in this league. The nation's GDP totals almost as much as all members of ASEAN combined (Figure 2). Furthermore, it was Australia, in partnership with the Republic of Korea in 1989, that stimulated the development of the Asia Pacific Economic Cooperation forum (APEC), the regional economic organization that is driving the opening up of Asia's leading-edge trade relations.

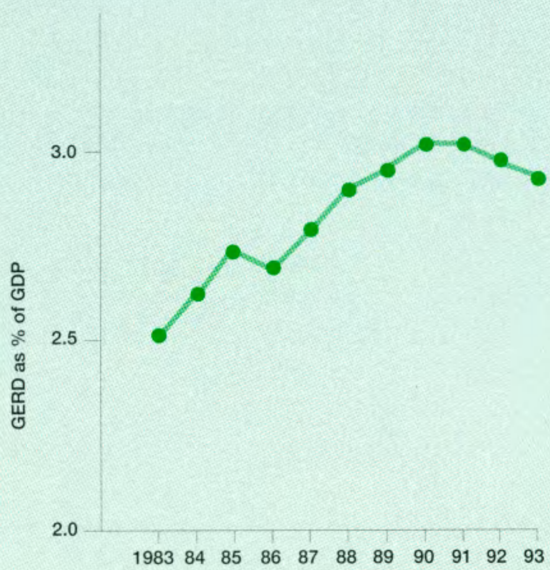
Asian economic growth and a developing regional identity expressed in both economic and political terms therefore constitute a major new force within the world economy.

SCIENCE AND TECHNOLOGY COMMITMENTS: DRIVERS OF CHANGE IN ASIA

Most importantly, the leading-edge of change in the region is knowledge-led. With an economy that is now based on its ability to capture and exploit knowledge, Japan is at the forefront in the region in both the absolute volume of expenditure the nation makes on research and development (R&D) and in the consequent ratio of gross expenditure on R&D (GERD) to GDP. The ratio of R&D to GDP peaked in 1990-91 at 3.02% and, with an expenditure of 13 709 billion yen, stood at 2.92% in the most recently surveyed year, 1993.

Japanese R&D is mainly supported by industry. The lion's share of growth in Japanese research

FIGURE 3
TREND IN JAPAN'S R&D EXPENDITURE



Source: STA Today (1995) *Journal of the Science and Technology Agency*, Japan Foundation for Science and Technology Promotion 7(1): 6.

expenditure (Figure 3) has arisen from industrial investment. The nation has become aware, however, that higher levels of government investment are now required both to stimulate the development of basic research needed for further industrial growth and to renew systematically the obsolete facilities and equipment of universities and centres of excellence.

Whilst Japan continues to be the leading R&D spender, science in the region is now far less dominated by the powerful economic position of Japan than it was during the 1980s. Sustained growth in R&D investment in many of the Asian newly industrializing countries and economies has meant that their levels of GERD as a percentage of GDP are rapidly moving to the levels of investment experienced in OECD countries. In 1981 the two fastest growing economies, Chinese Taipei and the Republic of Korea, were spending well below the OECD average on GERD (approximately 1.38% of GDP). However, they recorded high real annual growth levels through the 1980s – of 24% and 16% respectively (Figure 4) – so that by 1990 the Republic of Korea had moved up from 20th to 10th place in world rankings, and Chinese Taipei from 17th to 12th place.

Meanwhile Singapore's GERD has grown at a rate of 22% from a very low base of 0.28% of GDP in 1981 to

TABLE 2
CHANGE IN GROSS EXPENDITURE ON R&D (GERD) EXPRESSED AS % OF GDP IN SELECTED ECONOMIES

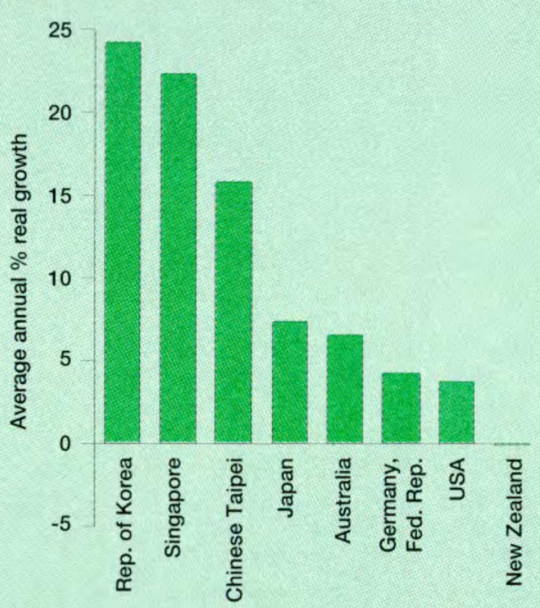
	GERD as % GDP	
Country/area	**1981**	**1991**
China	0.80	0.72[1]
Japan	2.13	3.02
Rep. of Korea	0.62	1.86
Chinese Taipei	0.93	1.69[1]
Indonesia	–	0.20
Malaysia	–	0.80
Philippines	–	0.20
Singapore	0.28	1.27[2]
Thailand	0.02[3]	0.16
Australia	1.00	1.34
New Zealand	1.01	0.88
USA	2.43	2.75
UK	2.37	2.08
Germany, Fed. Rep.	2.43	2.66

1. 1990.
2. 1992.
3. 1986.

Sources 1981: Selected country reports (Indonesia/Thailand/Singapore) and *Australian Science and Innovation Resources Brief* (1994), Australian Department of Industry Science & Technology (DIST). Based on OECD (1993) *Main S&T Indicators, No. 2* and NSF, 1993.

Sources 1991: S&T Analysis Section, Department of Industry, Science and Technology based on OECD and national data (OECD/STIID database as at November 1993, ABS 8122 and 5206, and S&T Analysis Section estimates).

FIGURE 4
AVERAGE ANNUAL REAL GROWTH IN GERD IN SELECTED ECONOMIES BASED ON CONSTANT 1985 PRICES – 1981-91



Sources: S&T Analysis Section, Department of Industry Science and Technology based on OECD and national data (OECD/STID database as at November 1993, ABS 8122 and 5206, and S&T Analysis Section estimates).

1.27% in 1992; Australia has increased its GERD as a percentage of GDP from 1.00% to 1.34% and China's levels of R&D investment grew very strongly, particularly in the non-state enterprise sector, yielding a GERD/GDP ratio which, though only a quarter that of Japan, is disguised in its significance by the radical shift in denominator: that is, by the enormous level of GDP growth that occurred in parallel. As a consequence, of the medium-level R&D performers, generally dominated by Sweden and Switzerland, the fastest growing R&D investing countries are now those from the Asia-Pacific region. Furthermore, whilst the amount spent on R&D per researcher in the Republic of Korea, Chinese Taipei and Singapore is currently about half that of the USA, the gap is narrowing rapidly.

The impact of these science-centred strategies is already being felt. Evidence of a science 'catch-up' is demonstrated in patent data. For example, as Table 3 shows, the Republic of Korean patents registered in the USA have increased by 400% in just the last four years. In 1990, the Republic of Korea registered half as many patents in the USA as did Australia, the second most successful patenting country in the region after Japan. By 1994, the Republic of Korea was registering patents

TABLE 3
PATENTS REGISTERED IN THE USA BY SELECTED PACIFIC RIM COUNTRIES BY YEAR

Country	1983	1985	1987	1989	1991	1993	1994	1983-94
Japan	8 804	12 756	16 569	20 177	21 028	20 949	22 384	204 597
Rep. of Korea	26	40	84	160	403	764	950	3 361
Brunei	0	0	0	0	1	0	0	2
Indonesia	0	1	1	5	2	4	8	37
Malaysia	2	3	2	2	13	13	12	66
Philippines	5	5	5	7	6	5	2	52
Singapore	5	9	12	19	15	39	54	213
Thailand	3	1	1	4	3	7	5	33
PDR Laos	0	0	0	0	0	1	0	3
Australia	237	341	386	501	458	372	470	4 701
New Zealand	39	33	69	58	40	38	36	566

Sources: CHI Research, Inc. (1995) Haddon Heights, NJ, USA; unpublished table of patent counts supplied to the Centre for Research Policy, University of Wollongong.

in the USA at twice the rate of Australia. Meanwhile, Singapore, starting admittedly from a very low base of 5 patents in 1983, increased its registrations by a factor of 10 by 1994, registering 54 patents.

The region is not, however, uniform in its R&D levels. Malaysia spends somewhat less than Singapore but retains a relatively high GERD/GDP ratio of 0.80% (see Table 2). Whilst Malaysia's development plans are increasingly manufacturing oriented, this research base is still largely in the public sector and its orientation towards agriculture-related development has only recently started to change. Elsewhere in ASEAN the levels of expenditure on R&D as proportions of GDP are considerably less, being largely dominated by public sector funding, and reflecting the 'other' side of Asia: the developing country status that is still cast over the majority of populations outside the leading-edge economic zones. Further south, within Australasia, New Zealand has a GERD/GDP ratio close to that of Malaysia, at 0.88%, a figure that has dropped from 1.01% in 1981, but which reflects a nation that has radically restructured its government science base into competitively funded 'crown corporations' for which staffing levels temporarily dropped. The R&D expenditure levels in New Zealand are now starting to grow again along with New Zealand's purposefully oriented strategy to build a manufacturing and export capability on its agricultural base. The situation in Indonesia, the Philippines and Thailand reflects a less advanced industrial country status. All spend approximately 0.2% of GDP on R&D.

HUMAN RESOURCE DEVELOPMENT

The science and engineering human resources base from which the less industrialized countries are starting their current drive to capture advantage from science is relatively low. Consistent indicators are very difficult to obtain, however. As perhaps the best data, Table 4 identifies the level of this indigenous research training base across selected Asian countries in terms of two indicators: ratio of postgraduate education to tertiary education generally and, within this, the ratio of postgraduate education in science and engineering to total postgraduate education. The relatively high percentage of postgraduate training to bachelor level training shown in the data for Australia and New Zealand is a product of mature tertiary education systems that are now offering a wide range of coursework Masters degrees in addition to traditional postgraduate training. Elsewhere, as would be expected, attention to research training is highest in the countries that have recently developed a strong S&T base and which currently place a high priority on endogenous S&T-led development: the Republic of Korea and Singapore. Table 5 demonstrates that these two countries have relatively high levels of scientists and engineers as a proportion of their population, with Singapore demonstrating almost the same levels as Australia and growing very fast. Japan remains, however, well ahead, with twice Australia's and Singapore's scientist and engineer concentration. What is more instructive is the level of concentration within endogenous research training on science and engineering. The People's Republic of China stands out, with three-quarters of all postgraduates being trained in science and engineering. Japan retains strength in this area as well, with over half of its postgraduates being trained in these areas. However, the proportionate concentration across other countries – including the Republic of Korea and Singapore – is lower, standing at approximately 20-25% of the overall number of postgraduates educated, with the Philippines lower still at 8.65%.

These figures on domestic research training, however, tell only a part of the story. Much of the research training for Asian countries is completed in the advanced country universities of Europe, Australia and North America. For example, 46.1% as many doctoral science degrees and 21.1% as many doctoral engineering degrees are awarded in the USA to Chinese nationals as in China itself; equivalent

TABLE 4
TERTIARY EDUCATION ACROSS SELECTED PACIFIC RIM COUNTRIES

Country	Year	No. students at tertiary level	No. postgraduate students: Science	Engineering	Others	Total	% postgraduates of total no. students	% science and engineering of postgraduates educated
Australia	1991	534 538	21 178	5 698	66 027	92 903	17.38	28.93
China	1991	2 124 121	22 806	36 942	20 711	80 459	3.79	74.26
Japan	1989	2 683 035	23 233	30 934	31 096	85 263	3.18	63.53
Rep. of Korea	1991	1 723 886	15 460	13 019	64 120	92 599	5.37	30.76
Malaysia	1990	121 412	1 012	239	3 730	4 981	4.10	25.12
New Zealand	1991	136 332	2 461	402	10 929	13 792	10.12	20.76
Philippines	1991	1 656 815	4 704	816	58 274	63 794	3.85	8.65
Singapore	1983	35 192	144	388	1 337	1 869	5.31	28.46
Thailand	1989	765 395	3523	1 405	16 116	21 044	2.75	23.42

Note: Based on the UNESCO classification of engineering and science: science students include natural science, mathematics and computer science, medical and health-related.

Source: UNESCO (1993) *Statistical Yearbook, 1993,* Paris: UNESCO.

TABLE 5
SCIENTISTS AND ENGINEERS IN SELECTED PACIFIC RIM COUNTRIES

Country (year)	No. scientists and engineers per million population
Japan (1989)	5 183
Rep. of Korea (1988)	1 343
Indonesia (1988)	181
Malaysia (1988)	327
Philippines (1984)	90
Singapore (1992)	2 305
Thailand (1991)	107
Australia (1991)	2 449

Source: UNESCO (1993) *Statistical Yearbook, 1993,* Paris: UNESCO.

Australia: Department of Industry, Science and Technology (DIST), *Australian Science and Innovation Brief 1994.* Aggregated from detailed field of research data provided to DIST by ABS, June 1993.

Singapore: National Science and Technology Board, *1992 National Survey of R&D in Singapore,* Table III.1, 18.

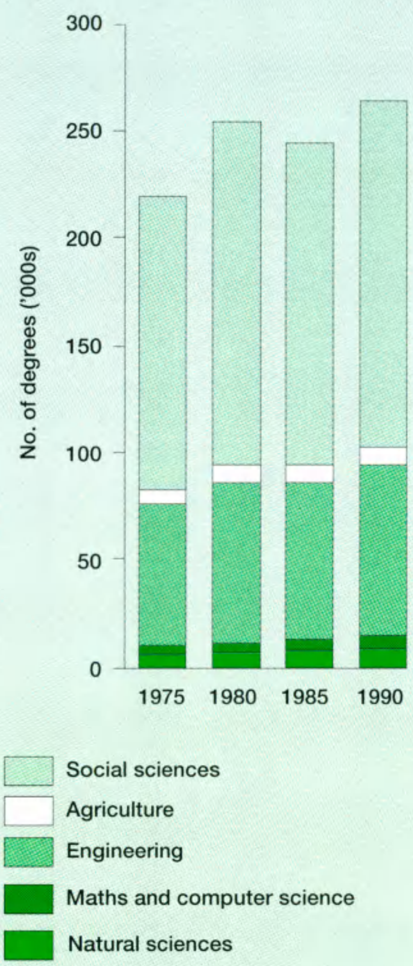
Thailand: Based on National Research Council, Ministry of Science, Technology and Environment (MOSTE) *Study of R&D Expenditures and Personnel in Thailand in 1987-1991.* Collected by Science Indicator Section (OSTEPP).

percentages for science and engineering doctorates for Republic of Korea students are 46.2% and 44.4% respectively, and for Chinese Taipei, 81.1% and 73.6%. The situation can be expected to be similar for most ASEAN countries. Japan, on the other hand, has a much lower dependency on American doctoral degrees, with USA figures representing only 5.6% and 1.8% of the numbers of science and engineering doctorates respectively awarded in Japan.

What is striking about the ASEAN nations, however, is that whilst current GERD expenditure may be relatively low, the nations have all embarked on strong programmes to build their S&T capability, particularly through investment in human resource development.

In 1980, Singapore, for example, had nine research scientists and engineers per 10 000 of its workforce. In 1990, there were 28, rising steadily towards Singapore's 1995 target of 40 research scientists and engineers per 10 000 of the workforce. Meanwhile, the number of research scientists and technicians in Singapore grew from 6 046 to 9 193 between 1990

FIGURE 5
BACHELOR DEGREES IN SCIENCE AND ENGINEERING IN JAPAN BY FIELD, 1975-90



Source: NSF (1993) 93-303.

and 1992. Singapore's growth is fueled by a current major five-year investment of over US$1 billion to strengthen industrial R&D under the National Technology Development Plan; similar programmes exist in Indonesia (US$90 million), Malaysia (US$150 million) and Thailand (US$50 million).

These human resource development (HRD) strategies have been strongly influenced by the examples of Japan and the Republic of Korea. As part of the reconstruction after the Second World War, Japan made a concerted effort to increase the number of science and engineering (S&E) degrees awarded and to double its gross national product. Because of its investment in S&T human resources over the past three decades, Japan now produces a quarter of a million S&E degrees each year, though with a relatively small base in natural science (see Figure 5).

Currently, Japan enjoys a ratio of S&E personnel in R&D per 10 000 of the workforce of 74.9 (in 1990), and 6% of all 22 year olds are enrolled in natural sciences and engineering university degree courses.

The Republic of Korea is fast catching up. At the end of the Second World War only 2% of the Korean population over 14 years of age had completed secondary school, and the illiteracy rate stood at 78%. Since then enrolments have increased over five times in elementary school, 28.5 times for secondary school and almost 150 times for tertiary education. Heavy investment in HRD in the early years resulted in short-term unemployment problems for the educated, but laid a critical foundation for the nation's subsequent economic development. Based on this platform, between 1975 and 1990 the Republic of Korea tripled its university enrolments and in 1990 36% of Korea's youth in the 20- to 24-year-old age group were attending universities, with the same proportion enrolled in natural sciences and engineering degrees as in Japan (6% of all 22 year olds). Over the same 15-year period, the percentage of the equivalent cohort in Chinese Taipei enrolled in universities rose strikingly from 16% to 27%, whilst in Singapore it rose from around 7% to almost 20%.

PLANNING AND DECISION-MAKING STRUCTURES

Meanwhile, since UNESCO's 1982 Second Conference of Ministers Responsible for the Application of Science and Technology to Development in Asia and the Pacific

(CASTASIA II), and the focus this Conference gave to the need for relevant and industrial demand-led national science, there has been a strong drive through the South-East Asian region towards the development of national science policy structures and their integration with economic planning (Raman and Hill, 1982). As a part of these developments, the types of formal institutions for driving science policy that have long been part of the science systems in the industrially developed countries were set in place in countries that previously had only limited science infrastructures. Such institutional developments included the establishment or strengthening of S&T councils, S&T ministries, science academies and new research institutions. Taking Thailand as an example, the Applied Scientific Research Corporation was established under the nation's Second Economic Development Plan of the late 1960s, and a Technology and Environment Planning Division focusing on managing the environmental consequences of industrial development was formed in the late 1970s. However, it was not until the early 1980s that the nation's Ministry of Science, Technology and Energy was established under Thailand's Fourth Plan, and not until the late 1980s that S&T became an explicit part of national development planning under the Fifth Plan.

Strong attention has, in parallel, been paid to building decision-making capability. Australia played a supportive role in this through development assistance-based training programmes in S&T management and policy for ASEAN countries through the mid-1980s, whilst the ASEAN Council for Science and Technology (ASEAN-COST) and the UNESCO-based Science and Technology Policy Asian Network (STEPAN), which was founded in 1988, prioritized and supported the development of S&T management information systems and training throughout the region.

Furthermore, in both the ASEAN and North Asian regions, many of the countries have now developed long-term S&T planning strategies as a component of their general economic strategies. Malaysia, Indonesia, Thailand, Singapore and the Republic of Korea have all developed science and technology plans that project well into the 21st century. For Indonesia, their Science and Technology for Industrial Development (STAID) programme is an integral part of the government's effort in transforming a predominantly agrarian economy into an industrial one. Particular attention is placed on leading industrial development through 'strategic industries', especially aeronautics, and thence energy, telecommunications and so on. The Malaysian 'industrial master plan' now incorporates an Action Plan for Industrial Technology Development (APITD), set within the Prime Minister's concept of a Malaysian '2020 Vision'. Supported by a recent Intensification of Research in Priority Areas (IRPA) programme, it sets Malaysia on a strategic path of technology development. Singapore aims to achieve the status of a developed nation by the year 2000 and, in the context of its severe limitations in resources, has recognized the indispensability of technological innovation and therefore promotion of R&D. All these nations are paying explicit attention to the example not only of Japan, but of the Republic of Korea, where both long-term infrastructure support and singularly industry-based R&D have produced extraordinary gains in competitive economic performance. Indeed, in response to this attention, the Republic of Korea inaugurated an explicit S&T policy development assistance programme for ASEAN nations in 1994.

In both the more advanced and the developing members of the North-East and South-East Asian groups of countries, that is across the Pacific Rim, there is a clear and strong commitment to nurturing scientific and technological enterprise as the universally accepted wellspring of economic development and competitiveness.

THE INCREASING CONNECTEDNESS OF ASIAN SCIENCE WITH THE WEST

As a result of this commitment, scientists across Asia are increasingly able to work in Asia with similar institutional and salary support to their North

American or European counterparts. An indicator of this change in Asia's environment for science is that whilst the number of students going abroad to study continues to grow, more and more are drawn back home by better salaries and working and living conditions. Indeed, many scientists who have long worked abroad are returning to their own countries to play a leading role in managing new, well equipped institutes and to use their experience to bring their nation's research up to leading-edge international standards. As *Science* (1993) comments, 'the once lamented brain drain is proving to be a brain reserve of immeasurable worth':

'Sprinkled across Asia are the magnets for their return: glimmering palaces of research offering world-class equipment and generous budgets. Facilities like Taiwan's [*sic*] 1.3 GeV Synchrotron Radiation Research Center (SRRC) which will be one of the world's most powerful radiation sources when it opens this fall, and Singapore's Institute of Molecular and Cell Biology (IMCB), which in 6 years has earned a glowing reputation, are putting the Asian Tigers on the world's scientific map. In Hong Kong and South Korea [*sic*] lavishly funded new research universities are attracting hundreds of midcareer professors from the United States' (Kinoshita, 1993: 348).

These movements back to Asia of scientists trained and experienced in work in advanced industrial countries reflect the new engagement of Asia – across both the 'Tigers' and in the less developed counterparts – in the global S&T order of the 1990s. Recent evidence demonstrates that fundamental to success both in leading-edge scientific endeavour, and in transfers of scientific knowledge to industrial application, is the transfer also of 'tacit' or non-formal disciplinary knowledge (Hill *et al.*, 1994; Hill and Turpin, 1995; National Board of Employment, Education and Training, 1995; Gibbons *et al.*, 1994). Research globally in the 1990s is increasingly set in the context of industrial application and is therefore increasingly characterized by multidisciplinary teams, where the ability to organize knowledge from the variety of disciplinary 'shelves' and link it with application requirements is critical. Transfer of knowledge is therefore very closely associated with the movement of people who have built up the tacit knowledge skills that leading-edge research now requires.

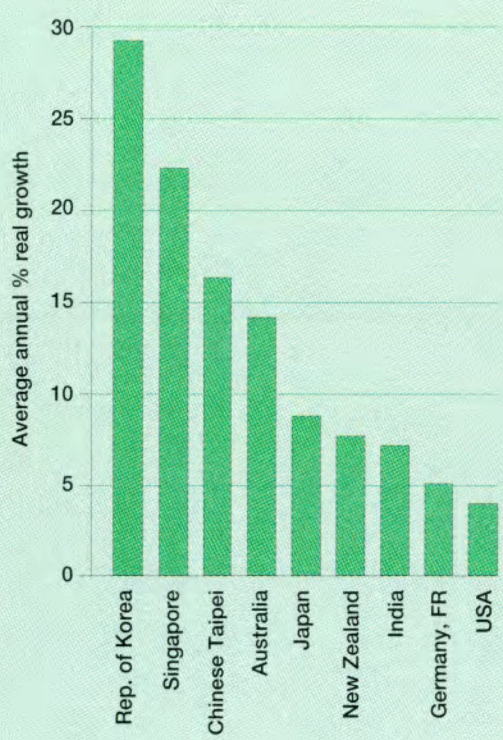
THE COMMERCIAL EDGE

An increasingly intimate relationship between research and application has been injected into global science by the immensely competitive market demand for new knowledge that has built up during the 1980s. Except through such tacit knowledge transfers, the leading-edge of science is therefore no longer available to new national or corporate players as it was earlier in the 20th century. Instead, new knowledge is more likely to be 'shrouded in secrecy', crossing international borders within a corporate entity rather than being available as a 'collective pool of accessible scientific findings' (Hill, 1995). Governments throughout Asia have recognized the difficulties that arise for public sector-generated research to be applied within industry. As a result, there is a universally increased emphasis on generating R&D within the business sector and to developing new mechanisms for the more effective commercial use of public sector research enterprise.

Indeed, the growth rates of business sector R&D funding among Asia-Pacific economies have generally increased at a faster rate than those of countries within the OECD. The Republic of Korea, Singapore, Chinese Taipei and Australia, for example, rank above the list of all OECD countries in terms of their growth in business sector R&D funding between 1981 and 1991 (see Figure 6). Whilst their base levels of business sector funding are high (60% of GERD in the case of Japan), the UK, Japan, USA and Germany, in contrast, all recorded less than the average growth in business sector funding (9.2% per annum) over the same period. By 1992 in Singapore, the private sector contributed 60.8% or Sing$578 million (approximately US$350 million), to national R&D spending.

The less developed economies are still having some difficulty in generating business R&D expenditure and are exploring a range of supportive policy mechanisms to assist. These include tax incentives, the development of S&T 'parks' and business incubators, and increased pressure on public sector research to be

FIGURE 6
INTERNATIONAL RANKINGS OF SELECTED ECONOMIES BY GROWTH IN BUSINESS SECTOR FUNDING OF R&D BETWEEN 1981 AND 1991



Sources: Department of Industry Science and Technology (DIST) (1994) *Measures of Science and Innovation 4*, Table 3.4, Canberra: Australian Government Publishing Service. The base international data are from OECD (1993) *Main Science and Technology Indicators, No. 2* and NSF (1993).

of direct commercial stimulus to industry. Australia and New Zealand, whilst both of advanced nation economic status, are also relatively small players on the world technological scene and both have also had difficulties in generating adequate commercial application of research and business R&D expenditure. New Zealand has radically restructured its public sector research, turning previous government agencies into 'crown corporations' that now compete with each other and private enterprise for 'contestable' research funding. Australia has introduced a general rule across its government research establishment that requires 30% of funding to come from external earnings beyond government appropriations and, perhaps even more significantly, also introduced a major new organizational experiment in the form of Cooperative Research Centres, of which there are now approximately 60. These organizations bring together academic, government and industry interests into new networked institutional structures focused on key Australian research strengths.

INTELLECTUAL PROPERTY RIGHTS

Furthermore, the increasingly generalized attention to the international 'flows' of knowledge and commercial application throughout the region has led to remarkably rapid movement towards harmonization of intellectual property legislation. Whilst the advantage of harmonized legislation for the advanced industrial players has been obvious for some time, the 'catch-up' countries of the region have now also recognized that their alignment with internationally accepted intellectual property legislation creates a more attractive climate for potential technological and capital investment from abroad. Consequently, although countries such as Malaysia, the Philippines, Thailand and Indonesia remain highly marginal technology generators in terms of international patenting, they have taken part in the regional trend towards harmonizing intellectual property law concerning patents, copyright, designs and trademarks. For some countries, such as China, legislative frameworks have been introduced as part of the major reform of the entire legal system that is associated with the nation's radical economic restructuring. Legislation concerning specific technologies, such as those related to generation of plant varieties or integrated circuits, has already been introduced amongst the more industrially developed countries in the region. Further harmonization is a high priority within APEC.

INTERNATIONALIZATION AND COOPERATION

To capture the flows of knowledge that an increasingly globalized knowledge economy represents, many of the nations of Asia are paying increasing attention to internationalizing their R&D capability, and thus gaining access to knowledge that otherwise is transferred across national boundaries behind the closed walls of multinational organizations. This internationalization is being carried out in a variety of ways. The internationalization of Japan's R&D effort has been associated with the establishment of major R&D centres in Western countries: for example, Canon in France, Kobe Steel and Sharp in the UK, Matsushita Electric in Germany and, in the USA, Hitachi in California, Kyôcera in Washington, Matsushita Electric in San Jose, Mitsubishi Electric in Boston, NEC in Princeton and Nissan in Detroit and Bedford. Meanwhile, Japan's domestic corporate research base, whilst increasingly connected to the international scientific literature, remains more dependent on Japanese R&D than on any other country's. This is partly because of language barriers and geographic distance, but particularly because of the high relevance of localized research networks within the Japanese cultural context (Hicks *et al.*, 1994). On the other hand, Japan has recently been paying attention to internationalizing its university student population. In 1983, Prime Minister Nakasone Yashuhiro pledged that Japan would host 100 000 foreign students a year by 2000. The numbers have risen rapidly, with 48 561 foreign students studying in Japan in 1992, more than four times the 1982 figure, almost 30% of whom were majoring in science, engineering or medicine (Normile, 1993).

In the case of the Republic of Korea, the greatest contemporary difficulties being faced concern 'growth bottlenecks'. Until now the country has relied on imported technologies to generate rapid industrial growth. But as the technology gap between the Republic of Korea and the fully industrialized countries has narrowed it has become increasingly difficult to progress further whilst building on imported technologies. Meanwhile, the science and engineering knowledge required remains largely controlled within multinational corporate enterprises and not easily accessible. The Republic of Korea's response has been commitment to a programme of domestic and international cooperative R&D ventures, to link academic and business interests effectively and to extend such networks into the international domain. The Cooperative R&D Promotion Law, 1993, has recently been introduced to promote such collaboration. Attention is also being paid to using these emerging cooperative activities to provide the training ground for specialized science personnel. In 1994, 11 research institutes and 13 universities were participating in joint industry-academic research institute cooperative postgraduate programmes that are specifically dedicated to the production of future R&D personnel.

Entry to the internationalization arena requires the ability to contribute at a level that is valued by internationally cooperating partners. The less developed nations of Asia thus remain at a disadvantage. Publication level may be taken as a measure of international participation by a national scientific establishment, and it must be said that the performance of ASEAN countries in the international literature is limited. As an indicator, the number of research articles across all fields of science, captured by the citation service run by the Institute for Scientific Information (ISI) for the period 1983-86, from Indonesia totalled 373, from Malaysia 810, from Thailand 1 062 and from Singapore 1 190. In Indonesia and Thailand there was a strong association between international publication and foreign collaboration, though a relatively small level of collaboration (as also in Malaysia) at a national level, suggesting weaknesses within the nations' own S&T concentrations. Whilst international journal publication is only a very partial indicator of the national strength that can be brought to the international S&T bargaining table (particularly in countries like Indonesia and Thailand, where language is a barrier), the indicator is still valid as a measure of international participation. Significantly, a feature of the distribution across fields within the international publications of scientists from ASEAN countries was that in Malaysia and Thailand, as in Indonesia, clinical medicine and biology accounted for the majority of research articles, while there was relatively little activity in engineering and technology. This contrasted strongly with the publication patterns of the newly industrialized countries of Singapore and the Republic of Korea, where engineering and technology were much more significant and were growing much faster than biology. These distinctions reflect the variation in leading-edge contact of the nations' scientific establishment with manufacturing industry. It should also be pointed out, however, that aggregate bibliometric indicators obscure the centres of excellent research that are now starting to emerge in specific areas around key scientists across all the nations of the Pacific Rim.

In spite of these variations in national strengths, international cooperation is seen generally across Asia as a way of overcoming the relative isolation from the scientific mainstream that these publication figures represent. However, most researchers from the North-East and South-East regions of Asia still predominantly form these cooperative relations with scientists and institutions from the more advanced industrial countries of Europe and the USA rather than with other nations of Asia. These networks partly follow the relationships established in student days.

However, there are signs of change emerging, partly as a result of personal links made by Asian students while in the USA or Europe, together with the upgrading of scientific infrastructure and mission at home. For example, an association established in 1983 to strengthen relations between Chinese-American scientists and their Pacific Rim counterparts, the Society for Chinese Bioscientists in America (SCBA), is now increasingly reaching across the Pacific, having met in Hong Kong in 1990 and Singapore in 1992. Many of the researchers are now returning home from the USA to Chinese Taipei, Singapore and Hong Kong because of better opportunities, and are maintaining their cross-Asian networks from their new positions (Kinoshita, 1993; Stone, 1993).

CONCLUSIONS: THE FUTURE FACE OF SCIENCE AND TECHNOLOGY AROUND THE PACIFIC RIM

The countries of the Pacific Rim – East and South-East Asia and Australasia – are increasingly involved in Asian-oriented trade and, meanwhile, within the framework of APEC, are beginning to cooperate in shared agendas to liberalize trade and harmonize standards and intellectual property rights legislation. Attention across the Pacific Rim is therefore focusing increasingly on its regional status and endogenous models for others' development. Science and technology capability are universally seen through the region as the driving force behind national economic competitiveness. As a result, across the Asian members of the Pacific Rim, strong investment in S&T human resource development is a major priority, as is improvement in the management of these national S&T resources to steer the nations' science towards effective commercial application. Previously, the less developed nations looked towards the USA and Germany for models of success. Today, much more attention is being paid by the less developed countries of East and South-East Asia to other Asian economies that are now growing much faster than those of OECD countries and investing much more seriously in science: that is, in addition to Japan, the Republic of Korea, Chinese Taipei and Singapore. The countries of the Pacific Rim in the 1990s are therefore beginning increasingly to cohere around a regional economic identity in which science is a central feature of development strategy. Though expressed in different ways in different countries there is a general drive to turn public sector science towards the marketplace, and to look for future S&T growth and application within the business sector. Generally, countries of the region are also investing and planning for S&T in the long term. Within this context, however, the manner in which the priority accorded to S&T is being realized is different in each nation.

Indonesia, for example, is still at a comparatively early stage of technological transformation of the economy. Nearly three-quarters of total manufacturing output is in industries featuring products with a low-technology intensity. Consequently, small-scale industry and the informal sector are prioritized for support. In parallel, however, development of sophisticated technological capabilities within 'strategic' industries, such as aeronautics, energy and electronics, is a strategy that is strongly supported as a means of 'pulling' the economy out of its developing-country status. Two key issues confront the nation's science policies. The first is redressing the shortage of skilled engineers and scientists, particularly those with higher degrees. Under international loan funding Indonesia established the Science and Technology for Industrial Development (STAID) programme to enrich the S&T resources and set the stage for industrial 'take-off' during the country's Sixth Five Year Plan, which takes Indonesia to the turn of the century. The second key issue for Indonesia concerns the low participation of industry in R&D. Currently only 30% of Indonesia's R&D expenditure is the responsibility of the private sector. Long-term policies are directed towards raising this proportion to 70%. Both the Philippines and Thailand share the policy concerns of Indonesia for S&T human resource development.

Brain drain from Indonesia is relatively low. Graduates trained overseas tend to return home. In **the Philippines**, where the culture is more Westernized through prior American influence and literacy rates are very high, brain drain is a significant problem. Within this context the Philippines has established an Engineering and Science Education Project (ESEP) to provide an additional 3 000 scientists and engineers by 1998. Under the Philippines Science and Technology Master Plan (STMP) this HRD focus is complemented by developing an S&T culture to strengthen the S&T infrastructure and upgrading R&D capabilities in priority sectors, but at the same time linking endogenous S&T development with industry and technology transfer policies, and modernizing the production sectors through massive technology transfer from both domestic and foreign sources. Particular attention has therefore been paid to the development of appropriate legislation to encourage international technology flows.

In the case of **Thailand** there is an awareness within government that the strong growth of the 1980s is unlikely to continue unless national technical capability is significantly increased at all levels – from factory technicians to leading-edge research scientists. HRD to provide the technical support that industry needs to capture the international flows of technical and economic capital is therefore accorded the highest priority. Meanwhile, industry contributed strongly to the growth in Thailand's national R&D capability over the period 1986-91, being responsible for most of the increase in GERD as a percentage of GDP from 0.02% to 0.15%. Government policy is now placing stronger emphasis on technology flows and the development of endogenous technology than on R&D *per se*. Thailand places a high priority in further stimulating growth in private sector R&D involvement, as well as in expanding international S&T collaboration as a way of strengthening national capability. A particular feature of Thailand's planning for the 1990s is its focus for the first time on specific industrial sectors considered to be the most crucial for future Thai development. Strong support is being given to generic technologies – micro-electronics, information technology and biotechnology.

Malaysia has a well established public research institute base, though oriented primarily towards agriculture, a legacy of prior British colonial administration. Malaysia's task in research is to establish the resources required to nurture the nation's long-term '2020 Vision' as a manufacturing nation. Signs of these changes are already apparent. MIMOS, the electronics research institute, is starting to impact on the development of a national electronics industry, primarily through flows of highly qualified staff into industry; the Malaysia Technology Park outside Kuala Lumpur is attracting considerable international technology-based investment, and the IRPA grant system is starting to add an industrial perspective to existing leading-edge research. Malaysia is now paying particular attention to strengthening the institutional capacity that stands behind these initiatives and to establishing industry-public sector linkages. Industry is being targeted as the source of future growth in national R&D. Towards this end, MIGHT, the Malaysian Industry-Government Group for High Technology, was officially launched in 1993 by the Prime Minister to 'prospect' for industry R&D-based opportunities and mobilize technological and industrial capabilities.

Whilst Malaysia is still in transition, the **Republic of Korea** already has a strong and industry-based science infrastructure: half of the approximately 1 000 research institutions in the country are in private industry and half of these are heavily concentrated in the 10 largest *chaebol* (industrial conglomerates), particularly within the electronics and chemical industries. This capability was developed in association with committed HRD investment during the 1960s and 1970s and effective support for the development of a national infrastructure, and thence powered by very strong industrially led investment in R&D during the 1980s. By the end of that decade national investment in R&D was 15.5 times the level it had been just one decade earlier. However, success has led the Republic of Korea in its targeted technological market areas to the frontiers of knowledge, so that a traditional reliance on the reverse engineering of imported technologies must now be replaced by a more basic and visionary science. Central to the Republic's strategy therefore is the internationalization of its R&D base. Korean industry is following internationalizing strategies similar to those of Japan in also establishing laboratories in the West. Domestic and international cooperative R&D ventures are being encouraged, as is the more effective linking of academic and business interests as a prerequisite for extending these relationships into the international domain.

Chinese Taipei has an economy that is strongly dominated by small and medium-sized enterprises. The Industrial Technology Research Institute (ITRI) was established in the 1980s to address the small firms' lack of R&D participation. Within the Institute, a series of centres, focused on key technologies for Chinese Taipei, assess international technologies, discriminate between technologies to be imported and those to be developed locally, and seek to galvanize and network with industry. R&D personnel frequently flow from the Institute to industrial enterprise. For example, under ITRI, 47 Chinese Taipei companies have joined to develop notebook computers. Particularly through inter-firm collaborative support for research, Chinese Taipei's overall R&D investment has therefore grown to 12 times its previous size – from 6 to 71 billion New Taiwanese dollars – between 1978 and 1990. Chinese Taipei's recent National Development Plan provided US$18 billion in funding for R&D and technology development. Strategy involves moving away from hardware and towards software; an industrial park for software is therefore being established to accelerate the development of specialized domestic software industries.

Singapore has made major commitments over the last few years to S&T innovation, fully acknowledging the centrality of its R&D capability to its future economic survival. The institutional structure for S&T policy was significantly upgraded in 1991 with the formation of the National Science and Technology Board under the Ministry of Trade and Industry. This Board has prioritized the development of high-quality strategic research institutes – in information technology, cellular and molecular biology and manufacturing technology. Growth of the nation's scientific capacity, which was boosted by Singapore's investment in the late 1980s, has been particularly apparent in the private sector. The government is firmly encouraging further private-sector R&D investment and the attraction of leading-edge scientists from around the world to work in Singapore towards the possible generation of 'blockbuster' ideas that may be turned into products and even into the creation of whole markets. Efforts are being made to persuade multinational corporations to locate their highest value-added activities in Singapore, even if they move more labour-intensive production elsewhere. In parallel, the new breed of 'technopreneur' (indigenous technologically innovative entrepreneur), which started to become successful in the late 1980s, is also being encouraged.

Japan remains the dominant science and technology power in Asia. The nation has, however, traditionally depended on its industrial sector to take the lead role in R&D. Universities have tended to play a relatively small role in the national innovation system, except as selectors of high-quality talent and as a source of networked links with both national and international scientific communities. Japan, like the Republic of Korea, must now take a leading role in the creation of new basic research knowledge. Increasing basic research is no longer stated as merely important, but as urgent. Japan, building on 1980s commitments to basic technologies for future industries, new materials, biotechnology and 'new function elements', and on its 1986 investment in the Frontier Research Program, is now focusing on science to deal with global problems, and on megascience. Currently, attention is being paid to upgrading significantly support for infrastructure and research throughout the university sector and national research institutes.

Australia and **New Zealand** both have strong basic research traditions, but have recognized too heavy a reliance on public sector funding that did not produce an adequate stimulus to national industrial innovation. New Zealand responded with a comprehensive restructuring of public sector research to foster greater competitiveness, and has prioritized its relatively small resource base towards research on agriculture-based manufacturing whilst increasingly moving towards closer science and technology industry linkages with Asia. Australia is similarly fostering closer S&T and industry ties with Asia, emphasizing the formation of partnerships in areas of national research strength that are related to development and to the infrastructure 'walls' that Asian nations are confronting as a direct result of their own rapid growth. Within Australia, emphasis has been placed on making both academic and public sector research more competitive and targeted towards commercial outcomes whilst at the same time building business participation in R&D. Business sector funding of R&D therefore doubled between 1984/85 and 1991/92, as did business funding of academic research, whilst business support of public sector R&D within the Commonwealth Scientific and Industrial Research Organization (CSIRO) increased fivefold to 21.4% of total CSIRO funding. Particular attention is now being paid to building linkages within the national innovation system, for example, through well funded S&T business networking programmes and the academic/public sector/business Cooperative Research Centre programme.

The face of science and technology across the Pacific Rim therefore conveys a strong expression of vitality, experiment, rising self-confidence and commitment to building for economic competitiveness in the coming millennium.

As a concluding note, however, it should also be recognized that closely associated with debates concerning S&T through the region is a rising concern that there is a shadow side to the success yielded by the generally distributed rapid economic growth. The Asian Development Bank calculates for a start that for ASEAN nations alone US$1 trillion will have to be raised by 2005 to finance the infrastructure support that will be required for growth rates to be maintained (Bardsley, 1995). Very high investments need to be made in both the human resources and urban and communication infrastructures necessary to maintain S&T-led industrial enterprise. Furthermore, just developing technically skilled S&T resources is not enough. Successful participation in the global technology order that is emerging in the 1990s also requires organizational innovation and new types of social and managerial capability. Each of the countries of the Pacific Rim, starting from quite diverse cultural and organizational practices, has to confront impediments in these cultural and organizational practices both to capture international technological flows and to bring national R&D rapidly into commercial application. Furthermore, it must be remembered that outside the glow of the Pacific Rim's economic miracle there remains a shadow of underdevelopment that national S&T resources must address. In many cases, as modern technological change sweeps through the economy, the linkages between more traditional sectors and the remainder of the economy are broken. Often the problem is the non-alignment of technical quality standards, and national S&T enterprise is the only source of support for re-integrating the economic and technological pluralism that characterizes developing economies. Finally, rapid development has often left behind environmental neglect. Water supply, waste water treatment, solid waste management and sanitation services, for example, are therefore likely to be struggling to cope with the demands being generated by further rapid industrialization and urban development. Most nations of the Pacific Rim do not have well established R&D capabilities in environmental management. Equally, however, there is now a widespread recognition of the need. The Republic of Korea, for example, is spending US$1 billion over the current decade developing environmental technologies, and Singapore has made environmental technology a key area of the National Science and Technology Board.

An amalgam of the three perspectives that were represented in the inaugural S&T policy meeting in Asia in 1965 is therefore being played out in contemporary S&T practice across the Pacific Rim. The most successful path has been that of the Republic of Korea, and today this serves as a continuing model for many other nations throughout South-East Asia. The dominant feature of contemporary policy through the region is the attention that is being paid to ensuring close user-oriented linkage of the national S&T system. However, given the need to prioritize the use of scarce resources effectively within a highly competitive global economy, planning and priority setting are central features of policy in general. Finally, as new knowledge has become the most central driving feature of new industry, attention has also shifted back to generating and capturing leading-edge basic research as well.

At the time of writing this chapter **Stephen Hill** was Foundation Director of the Centre for Research Policy, established as a Special Research Centre or centre of excellence of the Australian Research Council. He has researched science, society and development issues throughout Asia for the last 30 years, and has been consultant at very senior levels to most governments and international organizations in the region. Professor Hill founded STEPAN, the UNESCO-based Science and Technology Policy Asian Network in 1988, as well as the Asia Pacific Economic Cooperation forum's human resources and industrial technology programme and network in 1991. He was appointed in June 1995 as Director of the UNESCO Regional Office for Science and Technology for South-East Asia, Jakarta.

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China

ZHOU GUANGZHAO

China was at the forefront of science and technology for more than 1 000 years and made outstanding contributions to human civilization. Many major accomplishments were achieved in the fields of mathematics, geography, astronomy and medicine as well as in smelting, ceramics, architecture and agriculture. The four great inventions of the magnetic compass, paper-making, gunpowder and printing offered to the world by the Chinese nation were technological achievements that have exerted tremendous influence on the historical progress of mankind.

It is interesting to note that these examples not only reflect and represent the highest standards and greatest achievements of ancient Chinese technology, but also reveal the major distinguishing features of traditional Chinese technological structure and their inherent connection with ancient Chinese social structure. The technological structure of a society depends on the social structure and its demands upon technology. Since a system of centralized power was the dominant feature of Chinese feudal society, so technologies that served this system – such as communication, transport, the development of the astronomical calendar, etc. – all enjoyed rapid development. Restricted for a long time to individual trades, however, these technologies, although reaching relatively high standards, could hardly revolutionize other trades or sectors of society. In addition, these technologies were inseparable from those craftsmen who mastered them, and they were handed down from father to son, from guild-master to apprentice or simply monopolized by the government. Examples of technology loss and repeated reinvention are to be found everywhere. What is worth noting is the fact that the development of traditional Chinese technologies was closely linked to the stability of feudal dynasties and was seriously affected by the collapse of those dynasties. This created a serious obstacle to the accumulation of knowledge and the transfer of technology.

If the flourishing of ancient Chinese technology was conditioned by the political and economic structures of society, the development of scientific theory and experimentation in ancient China was mainly determined by the traditional cultural structure. Any ancient theory of science bears closely on the philosophical outlook of the times. From the Qin Dynasty an ideological structure was formed in China with Confucian theory as orthodoxy, supplemented by Taoist theory. Confucian philosophy and its cognitive pattern played a positive role, allowing for the generation of scientific theories based on direct experience and the evidence of the senses, with special emphasis on the social science of governance (there was, of course, no lack of talented imagination and reasoning). Although the integration of nature and the human being was interpreted differently by different schools of thought, the form of that integration reflected contemporary science, whose outlook on nature gradually evolved from the mechanical character which had dominated for three centuries.

In general, while the development of science and technology (S&T) in ancient China had a long history and splendid culture before the 15th century, it was to lag behind world development thereafter. How this could have happened is still under debate. From the cultural point of view, the ancient Chinese scholars used to view a complex system as a dialectic whole and never bothered to analyse it in parts to find its internal structure and underlying mechanism. Logic and mathematics were not systematically developed and no academic school of the natural sciences was formed. At the same time, the low status accorded to technicians and merchants seriously hindered the emergence of new productivity and the development of contemporary S&T. The long stagnation of the basic infrastructure of the feudal society and the conservative and backward nature of the traditional empire also isolated China from the outside world and from the 16th century caused it to fall behind Western countries in science and technology.

The development of China's contemporary S&T can be traced back to the end of the 19th century and the early 20th century, when continual invasions demonstrated the weakness and the failings of the Middle Kingdom. China began to send out a large number of students to Western countries, and on returning home these individuals worked hard to popularize scientific knowledge, to set up industries, publish S&T journals and begin to establish scientific associations and research institutes. By 1928 the Academia Sinica and the Beijing Academy of Sciences had been founded. However, frequent wars and a weak economy made the rapid development of science impossible. It is only since the founding of the People's Republic of China in 1949 that the country's S&T endeavour has made significant progress. Thanks to 40 years of devotion and the efforts of the S&T community, China has established an S&T system with relatively complete disciplines integrating basic science, applied science, engineering design and development. Remarkable achievements have been accomplished and outstanding contributions have been made to the nation's development and social progress.

NEEDS: CHALLENGE AND OPPORTUNITY

As we near the end of this century, human society is undergoing a tremendous change. The depth, scope and speed of the development of modern science and technology are without precedent, and the interaction between science and technology and national economic construction and social development becomes even closer. What should be the process of developing China's science and technology under such circumstances, and what measures are to be taken? These are the questions that the Chinese scientific community is constantly studying and trying to answer. Two important aspects must be considered.

First, science is governed by its own objective laws of development. Therefore, in drawing up S&T policy these objective laws need to be followed. There are two driving forces for the development of science and technology: the innovative pursuit of solutions to natural mysteries and the practical impulse for the pursuit of science and technology generated by economic growth and social development. These two driving forces must be fully mobilized to pave the way for the smooth development of science and technology through the use of different operational mechanisms and managerial systems.

Second, the scope, speed and focal points of S&T development bear closely upon the basic national conditions and overall national strength. At present, these Chinese national factors or conditions are as follows:

Overpopulation

The population of China has doubled over the past 40 years, reaching 1.2 billion and accounting for one-fifth of humanity. Of these people, 80% are involved in agriculture. Even if family planning programmes in the rural areas are viewed optimistically, there still exists the possibility of future population growth which is expected to peak around 2030 at about 1.5-1.6 billion. The need to provide for the everyday requirements, education and medical care of such a large population constitutes a severe challenge to the development of the economy and to science.

Relative shortage of resources

The territory of China stretches over 9.6 million square kilometres, but of this desert, permafrost and arid areas make up a large proportion that is unfit for agricultural and animal husbandry, whereas arable land per capita population comes to less than 0.14 hectare. China's water resources rank first in the world, but the per capita share is only one-quarter of the world average. Forest coverage has shrunk to 13%, and the average per capita is about one-sixth of the world figure. Although deposits of coal, titanium, tin and rare earths are abundant, other key minerals such as petroleum, natural gas, iron, copper and sylvite are not present in quantity.

Serious environmental problems

Overpopulation and poor cultural and scientific management have resulted in the overexploitation of land, mineral deposits and forest resources, and the mushrooming of enterprises low in productive technology has brought about serious environmental pollution problems. All this puts heavy pressure on sustainable social and economic development.

Need for modernization of traditional industries

Although China has established a relatively complete industrial infrastructure and has, over a fairly long time, formed a material and technical base for industrial modernization, its economic development is based on the heavy consumption of resources. The majority of its industries are backward in technology and management, with poor product quality and low profits. China has one of the highest energy consumptions per unit GNP and one of the lowest productivities. There is, therefore, a major task before the country to upgrade its traditional industries through modern S&T and significantly to improve output.

These factors suggest that the right direction for China's social and economic development lies in the establishment of a resource-saving national economic system, and in reliance on S&T and the improvement of the quality of personnel.

STRATEGIES AND POLICIES FOR S&T DEVELOPMENT

As a giant developing country, China needs to make particular progress in the following aspects of science and technology:

- it should apply modern S&T (especially information and automation technologies) in the transformation of its traditional industries, and modern agricultural science and biotechnology in the upgrading of its agriculture;
- it needs to give priority to the development and industrialization of high technology;
- it should aim to achieve significant progress in certain major areas such as population control, environmental protection, comprehensive exploitation and utilization of resources and energy conservation;
- it needs to make important advances in basic and applied research.

During the 1990s, in response to the national goals of social and economic development, the strategy for China's S&T undertaking has been to take the modernization of industrial technologies and facilities for large-scale production as its main task, to monitor and protect the environment in order to develop selectively high technology and high-tech industries, to steadily strengthen basic research, and to strive to improve education and to build national awareness of science and technology.

Basic research is of great importance to economic construction and the improvement of the cultural attainment of the nation as a whole. China is a huge country. Merely by importing foreign technologies instead of raising the scientific and cultural standards of the entire nation it will not be possible to narrow the gap between China and the major industrialized countries, let alone make innovations in certain fields. It must have its own scientific capability for basic research. China is also a developing country, and the scale of its basic research should match its national strength; and the selection of research subjects and emphasis on development should first be integrated with the needs of national economic construction and social development. If this were not the case, the stable development of basic research could not be guaranteed. In this context, China needs to develop its basic research on a medium- and long-term basis by significantly improving the quality of its research personnel so as to lay a good foundation for rational development, to keep pace with advances in world science and to aim at making major contributions to knowledge in a few selected frontier areas. At the same time particular attention needs to be paid to applied research and the progressive strengthening of China's scientific capability in solving major issues in its national economy, social development and national defence. Basic research and applied research should be open to scientists throughout the country and elsewhere in the whole world; research staff should be mobile; and cooperation between the Chinese Academy of Sciences (CAS) and the universities needs to be further strengthened. The state is giving its support and guidance to basic research through natural science foundation funds and the implementation of a special nationwide programme, under the title 'Climbing Project', which supports research in certain important areas in the frontiers of science within the Pandeng Programme.

Development and achievements in high technology are a reflection of a country's national strength. In developing high technology, China needs to concentrate on a limited number of targets and emphasize certain key areas, to aim for high international standards and to give preferential support to those areas and projects with the potential for wide application and possible major breakthroughs. Meanwhile, efforts should be made to push forward the development of high-tech industries, encourage high-tech industrial development zones and speed up the process of commercialization, industrialization and internationalization of high technology through the promotion of international cooperation and market exploitation. The priorities for hi-tech development in the 1990s are in microelectronics, computers and software, communications and networks, biotechnology and automation. Efforts are also needed in the study of new animal and plant varieties, new biological products, new drugs and vaccines, and the transformation of renewable resources and their comprehensive utilization, as well as research and development (R&D) of new materials such as composite materials, structural materials, amorphous materials, superconducting materials and photovoltaics. Continuous emphasis needs to be placed on R&D in satellites and advanced combustion technology, remote sensing and hazard mitigation to enable China to expand its capability in mass education, environmental monitoring and resource saving. The state promotes work in these areas mainly through the implementation of the 863 Programme and the Torch Programme.

Whether or not population increase can be controlled, the quality of life of the population improved, natural resources rationally exploited and used, and the environment protected, all have an important bearing on China's future. Great importance is therefore attached to S&T related to social development; strengthening R&D in such important fields as population, medical care, social services, public infrastructure, environmental and ecological protection; and the monitoring and prevention of natural disasters. In the wake of the United Nations Conference on Environment and Development (UNCED) of 1992, China has formulated 'China's Agenda 21', and has strengthened its R&D in environment, ecology and natural resources.

The transformation of traditional industry using modern technology is an urgent task for China's economic development as well as a duty from which the Chinese S&T community cannot shrink. The development of industrial R&D needs to be focused on raising economic benefits. We should apply modern technology and management techniques, especially in electronic and information technologies, in order to transform the various industrial sectors, improve the precision and control of machinery and equipment, save energy and reduce material consumption, improve product quality, create a variety of new products and raise the productivity and international competitiveness of our products; in short to optimize industrial structure and production. Agricultural research should be strengthened and planned so as to enhance the process of agricultural development. At the same time, the popularization and dissemination of advanced agricultural technology and the rational readjustment of rural industrial infrastructure and employment need to be carried out in earnest. In this respect, the state has established the S&T Key Task Programme, the Programme for Combining Industry, University and Research Institutions and the Spark Programme in an attempt to direct the S&T community of the whole country towards the cause of economic development.

The state has formulated a series of policies and taken various measures for the successful implementation of these strategies. Examples include:

- improving the management of R&D funds to give preferential support to key areas and programmes;
- developing human resources to bring on new R&D talents and give full play to their initiatives;
- applying such economic measures as tax, price, loan and depreciation benefits to introduce and push forward S&T progress in enterprises and in rural areas;
- striving to create a stable, democratic and free academic environment for R&D work and actively to promote international S&T exchange and cooperation.

THE S&T SYSTEM: ORGANIZATIONAL STRUCTURE AND SYSTEM REFORM

An S&T system essentially consists of two components: the organizational structure and the operational mechanism. The former includes the management system and the executive organizations.

Compared with those found in other major countries, the Chinese S&T management system is relatively centralized, or at least conditioned by a unified policy. Due to the departmentalism caused by the state administrative and financial systems, the S&T system in China is a complicated multi-layer, multi-channel and multi-element network involving central government and the provinces, management departments and executive organizations and various sectors and industries. The government is at the centre of this network. It is the policy maker and major supplier of resources for science and technology, and the research institutions affiliated to it are the chief executors of S&T in China. The State Council is the supreme policy-making and management authority in charge of national S&T policies, and the State Commission of Science and Technology (SSTC), the State Planning Commission (SPC), the State Science and Industry Commission for Defence, the State Education Commission (SEC) and the Chinese Academy of Sciences (CAS), and the functional departments under the State Council, are the S&T management organizations at the state level. The corresponding units of the above-mentioned departments at the provincial, prefecture and county levels, as well as local industrial bureaux, make up the local S&T management organization, completing a multi-level management system. For historical reasons, the management and research systems in social science have until now been separated from those of natural science.

In the field of natural science and technology, China's R&D base is mainly made up of the CAS, R&D units attached to various government departments, institutions of higher learning and their affiliated R&D units, technological development units of medium and large industrial enterprises and technological development units run by collectives and individuals (see Table 1).

Among them, the CAS and R&D units attached to government departments are the strongest in terms of research capability. Although not great in number, they are superior in the distribution of R&D funds and human resources as well as research strength, and form the backbone of China's R&D undertaking. Recently, with the deepening of the reform of the economic system and with it S&T, technological development units run by collectives and individuals have increased dramatically in number, though only a few of them can claim real accomplishments in scientific research.

The above-mentioned institutions lay emphasis

TABLE 1
R&D ORGANIZATIONS IN CHINA

	1990	1993
R&D units attached to government departments	4 961	4 996
Chinese Academy of Sciences	123	123
Institutions of higher learning	806	814
R&D units attached to institutions of higher learning	1 666	1 802
Technological development units of medium and large enterprises	8 116	9 432
Technological development units run by collectives and individuals	8 523	55 000
Total	**24 195**	**72 167**

Source: State Commission of Science and Technology (SSTC), *Science and Technology Indicators in China: 1992* and *1994*, Beijing.

differently on particular fields and orientations in research. Basic research is mainly carried out by the CAS and key universities. Research organizations in medicine, agriculture and industry conduct some mission-oriented basic research, but their R&D work chiefly involves subjects with potential application closely related to their own fields and general and key technologies. R&D units attached to industrial enterprises mainly serve the technological development of their enterprises, while R&D units run by collectives and individuals focus on short-term projects that can lead to quick profits.

During the process of S&T system reform, it is noticeable that new forms of R&D organization have emerged successively on the basis of the original research institutions. Since 1984, for example, 155 state key laboratories have been set up in the CAS, plus some key universities with the support of the SPC. Meanwhile, the SEC and the CAS have set up a number of open laboratories. These state key and open laboratories have not only consolidated the superiority of traditional research disciplines, but also opened up new research fields and become important bases for training outstanding S&T personnel and developing academic pioneers for the coming generations. The state established 67 engineering and technological research centres by the end of 1993 in order to raise R&D standards in engineering and technology, to strengthen the links between research institutes and industry and to promote the transformation of research achievements into actual productivity. A number of technological development centres were also established in some 100 medium and large enterprises during 1993 and 1994. To attract and cultivate senior S&T talent, the government has set up 299 centres for young post-doctoral researchers in 96 universities and 69 research institutes. The development of these new organizations has had a great influence on China's S&T activities, and they are set to become the growing points of the new S&T system in China.

In addition to R&D organizations, there exist in China 45 000 S&T service units dealing with S&T information and literature, S&T consulting services, geological survey, meteorological observation, earthquake monitoring, mapping, environmental protection, patent application and technological market management.

All these institutions and organizations constitute China's huge S&T system. The government has always attached great importance to the effective management of this system so as to give full exposure to the enthusiasm of the S&T personnel and rapidly to apply R&D achievements to production. The reform of the S&T system during the last decade has been focused on the operational mechanism of this system, with the following basic points:

- Different appropriation and fund management systems have been adopted for different research organizations according to the nature of their research, and the ratio of funds for operational work to funds for research projects has been changed in favour of the latter. For basic research, a foundation fund is now established and more help is being given to those projects deemed to be the best according to peer review. Support is given through various state plans and programmes for research on resources, the environment, ecology, fundamental data and the study of principles and methodologies of universal and key technologies. Funding for research on technological development is obtained mainly from the market through technology and product transfer and cooperation with industrial enterprises. The state also provides a modest amount of funding.

- The independence and authority of the institutes have been extended, government interference has been reduced and the principles of market economy and competition have been introduced.
- The mobility of S&T personnel has been promoted, links among research institutions, universities and industrial enterprises have been strengthened and the exchange of information and personnel has been enhanced.
- While stress is placed on serving the national economy, continuous emphasis is given to basic research and there is a proposal to maintain a set proportion of basic research. Applied research and development is also getting increasing support among scientists and government officials alike.

The present reform of the economic and S&T systems faces long-standing problems accumulated in the process of historical and social development and has to change the value-concepts that people are accustomed to. This is why the process is an arduous and complicated one. At present, a striking issue is how far the research institutions should go towards the market. It is clear that obliging research institutions to be market-oriented whilst reducing resources, before a real improvement in the social environment is achieved, will possibly cause a loss of accumulated resources for the S&T community and will affect long-term S&T development. What is more, overemphasis on seeking profits will to a certain extent aggravate the self-contained nature of the research institutions, and be unfavourable to the integration of science and technology with the economy. The state is aware of these problems and is taking appropriate measures.

S&T INPUTS AND OUTPUTS

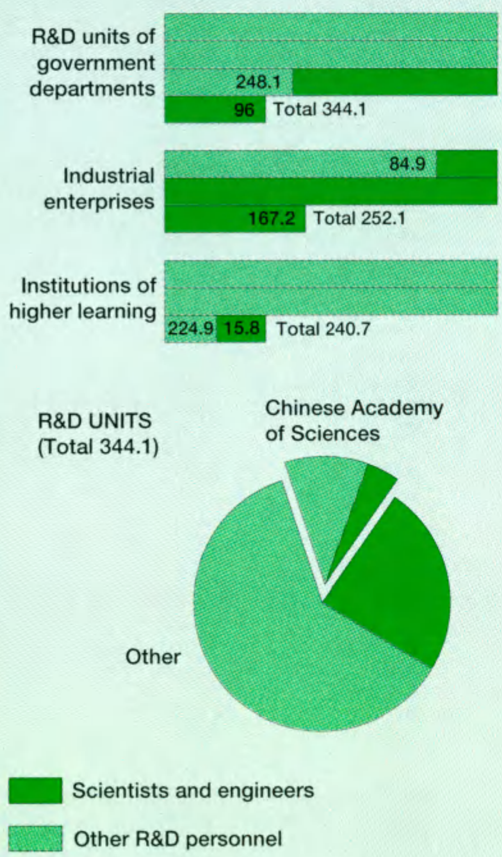
The following brief account of S&T personnel, funding and output is designed to illustrate the basic scientific infrastructure in China today.

Personnel

S&T personnel form the backbone of the development of science and technology. In 1993 there were altogether 2 426 300 S&T personnel (not including support staff in S&T service departments) in China. Of these 1 484 300 were scientists and engineers, or 61.2% of the total. In the same year the number of R&D personnel reached 916 800, including 598 200 (or 65.3%) scientists and engineers. Of all the R&D personnel, 344 100 are in the research and development units (see Figure 1).

The vitality of any S&T system lies in the continuous influx of new talent, and institutions of higher learning are the cradle for future scientists and engineers. In 1993 the total enrolment of under-graduate students in Chinese universities and colleges exceeded 2 536 000 and that of postgraduate students reached 107 000 (including 18 000 for doctoral degrees). In the same year, 571 000 undergraduates and 28 000 postgraduates completed their studies. Since 1990 the proportions of students majoring in science and technology have remained at 40% of the total undergraduate enrolments and 63.7% of the

FIGURE 1
DISTRIBUTION OF R&D PERSONNEL IN CHINA, 1993 (IN THOUSANDS)



Source: State Commission of Science and Technology (SSTC), *Science and Technology Indicators in China: 1994.*

postgraduates, and the proportion of doctoral students is even larger.

It would appear therefore that there exists a large population of Chinese S&T personnel and undergraduate and postgraduate students, but their relative numbers remain quite small since China has such a large population and S&T activities cover such a wide scope. If calculated as a percentage of the total population the S&T stock is not only far below that of industrialized countries, but also smaller than that of some developing countries.

The current reform of the S&T system has increased mobility and provided S&T personnel with greater opportunities for development. They are able to find positions that are both right for them and also appropriate for the needs of the country. Nevertheless, the reform process is also having some negative effects on the stability of the R&D contingent. Since the working and living conditions of S&T personnel are relatively poor, quite a number, especially amongst the young, go abroad or shift to commercial business. This drain of talent, accompanied by an ageing of the existing S&T community and the lack of qualified successors, has become a serious threat to the long-term development of science and technology in China and needs an urgent solution. Various measures have been adopted recently by the Chinese government and the CAS to attract young talent and to create better conditions within research for them.

S&T funding

S&T expenditure, especially that for R&D, reflects national S&T strength as well as the extent of support science receives from government and society as a whole. S&T funding levels are therefore an important indicator of the commitment towards science and technology and a key factor in the S&T endeavour.

The total national funding for S&T in 1993 was 19.6 billion yuan (US$2.4 billion), an increase of 2.7 billion yuan over the previous year. However, calculated at constant 1992 prices, the actual increase was only 0.66%, the smallest since 1988. In 1994 the total reached 22.2 billion yuan (US$2.7 billion).

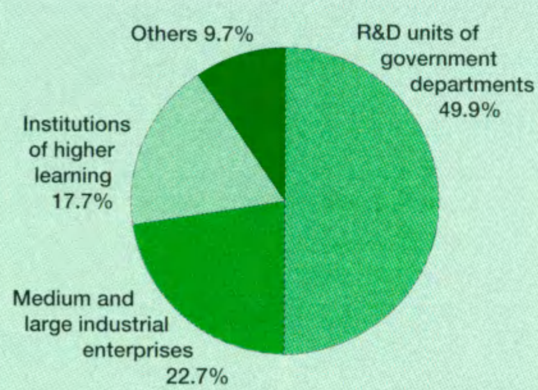
Since 1989 the ratio of R&D expenditure (GERD) to Chinese gross domestic product (GDP) has fluctuated around 0.7% and it fell to 0.62% in 1993. This indicates that the increase in R&D input is falling behind the development of the Chinese economy and its rapid growth in GDP. This ratio is far from that of the industrialized and the newly industrialized countries, and is lower than that of India.

Chinese R&D funding comes mainly from the government. Although industry makes some contribution towards science, very little of it is used for R&D work. From Figure 2 it can be seen that R&D units of the government departments are the main force behind research in China, the R&D ability of the industrial enterprises being relatively weak and that of the institutions of higher learning still being in need of development. No doubt this structural pattern in which the government takes pride of place is related to economic development, but it is also determined by China's existing S&T system. With the deepening of the reform of the system the situation is likely to change.

The proportions of R&D funding devoted to basic research, applied research and experimental development have remained basically stable in the 1990s, with that for basic research constituting only 7% of the total, lower than the international average.

In general, the shortage of R&D funding has seriously restricted the further development of China's science and technology. The Chinese scientific community hopes that, by the end of this century, the ratio of GERD to GDP can be increased to 1.5%, and that the proportion of funding devoted to basic research may be of the order of 10-20%.

FIGURE 2
DISTRIBUTION OF R&D FUNDING IN CHINA, BY TYPE OF EXECUTING ORGANIZATION, 1993



Source: State Commission of Science and Technology (SSTC), *Science and Technology Indicators in China: 1994.*

S&T output

The number of publications and the citation rate of scientific papers is a reflection of the output and the quality of S&T activities of a country and its position in the international scientific community. According to the statistics of the *Scientific Citation Index (SCI)*, ISTP and EI, 20 178 scientific papers published by Chinese S&T personnel were included in 1993, an increase of 9.2% over the previous year. For two years in succession China ranked 12th in the world according to the number of scientific papers published. As for the citation rate, 32 503 scientific papers were included in *SCI* from 1987 to 1992, with only 7 059 papers cited for a total of 12 896 times. This citation rate of about 0.22 was lower than the world average.

Patents constitute another key indicator in measuring S&T output. During the past two years, China's patenting system has been strengthened and there has been great progress in patent work. In 1993, patent applications numbering 77 000 were received and 62 000 patents were granted, an increase of 34.2% and 97.4% respectively over the previous year. Patent applications for inventions, utilities and exterior design constituted 25.4%, 61.5% and 13.1% of the totals respectively.

Evidence shows that scientific research has provided knowledge, theories, methodologies, thoughts and talent that have contributed to economic and social development in China, and a great number of S&T achievements have been turned into a productive force. In industry, scientific research has provided new products, new processes and new designs, and is the source of hi-tech products and hi-tech industrial processes. In the exploitation and utilization of natural

The Chinese Academy of Sciences

Founded in 1949, the Chinese Academy of Sciences (CAS) is China's leading academic institution and the comprehensive R&D centre in natural science and in the new and high technologies. As a national academy, it shoulders heavy responsibility in developing science and technology and in solving the major S&T issues raised in the course of national economic construction and social development. It has made and will continue to make important contributions to the life and well-being of the country.

The Academy is essentially made up of two parts. The first consists of the membership, selected from the most outstanding scientists in the S&T community throughout the country, and divisions composed of the members. At present, there are 560 members organized into five divisions (mathematics and physics, chemistry, biology, earth sciences and technological sciences). The second part is the research body of 123 institutes. At the end of 1993, the CAS had 81 500 staff members. Of these 50 600 (nearly 64%) were R&D staff, including 36 200 scientists and engineers, and 15 000 held senior titles of associate professor or higher.

R&D in the CAS ranges from activities in the basic sciences (mathematics, physics, astronomy, life and earth sciences) to such disciplines within engineering and technology as informatics, new materials, energy, space technology and so on. The fundamental task of the CAS is to deploy 30% of its R&D staff in basic research and innovative hi-tech research at the frontier scientific areas, 30% on natural resources, the environment, ecology and agriculture to protect and improve the quality of the environment and living standards, and 40% to serve the economy and the market and to solve key S&T problems in the transformation of traditional industries and the development of new ones. In the past 10 years, more than 500 hi-tech enterprises, with a total employment of 18 000, have been set up to integrate technology, industry and trade as an organic whole. The CAS has become one of the most important bases in the development of China's hi-tech industries.

Basic research is carried out in a number of institutes and key laboratories, as shown below. In 1994 the CAS set up two special scientific centres for work in the life sciences and the earth sciences to promote the interaction and integration of different research disciplines. Owing to the economic conditions, the shortage of funds for R&D work will not be solved in the short term. Therefore it is essential that good selections of research priorities and key areas be made. The CAS holds that key areas of basic research to be selected should:

- have a great bearing on scientific development and the national economy;
- be active frontier areas on a world scale;
- have a sound research basis, have access to good working facilities and offer the possibility of making significant breakthroughs.

According to these criteria, key areas for development in the CAS include such fields as condensed-matter physics, large-cluster chemistry, molecular biology, neural science and cognitive science, global change, astrophysics, non-linear science, nano-science and technology, environmental science, biodiversity, and fundamental problems in information, energy, materials and space technology.

BASIC RESEARCH AT THE INSTITUTIONS OF THE CHINESE ACADEMY OF SCIENCES

Institutions	No.	% of national research effort
Key laboratories	50	33
Open laboratories	63	66
Engineering and technology research centres	9	29
Centres for young post-doctoral researchers	62	21

resources and environmental protection, scientific research can provide basic rules, fundamental data and theoretical guidelines. In agriculture, medicine and other fields closely related to food and health, scientific research provides a basis for the cultivation of new varieties of plants and livestock, the development of new farming techniques and the effective control of insects, as well as theoretical guidelines for development and techniques. These facts are perfectly obvious, yet cannot be backed up with quantitative indicators. Since the 1990s China's economy has witnessed rapid and sustained growth, and the share of this contributed by science and technology has, according to the Solow Model, constituted 26.7%, a much lower figure than that in the industrialized countries. However, in the light of China's present economy, and compared with the past, we can fairly claim that science and technology are now making increasingly greater contributions towards economic development.

FACING THE WORLD: INTERNATIONAL S&T COOPERATION

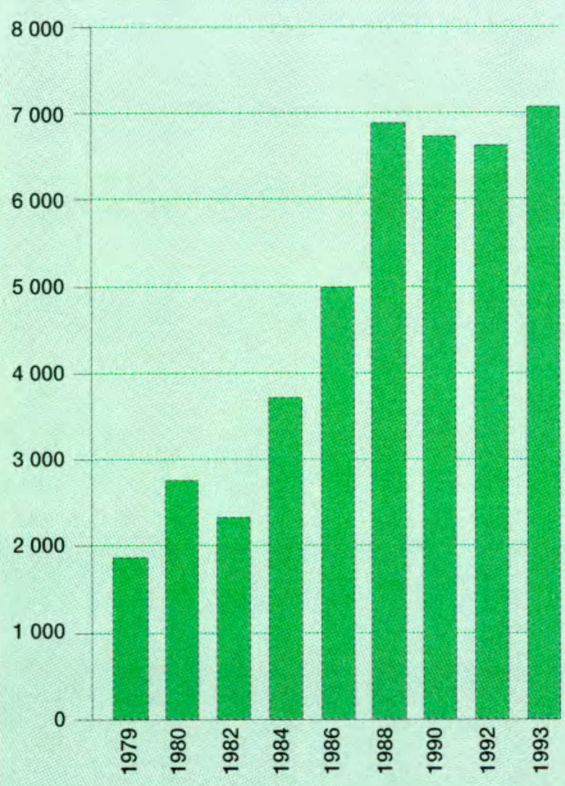
It has long been recognized that scientific research has no national boundaries, and that scientific achievement should be shared by humankind as a whole. In recent years, thanks to the rapid development of science and technology, the number of countries with significant numbers of qualified scientists, engineers and advanced research programmes has increased, and this has resulted in an increase in opportunities for transnational collaboration. Moreover, the cost of maintaining modern research systems is constantly rising, and it is increasingly clear that no single country can bear the investment needed for so-called megascience and high technology that is by definition expensive and risky. In this situation, international cooperation and cost-sharing are an absolute necessity. Furthermore, cooperation is required for tackling such global issues as population, the environment, resources and the natural disasters that confront humankind as a whole. Hence, the integration of opportunities and needs has tended to promote the emergence of an international S&T system. The internationalization of science and technology has become one of the major trends in S&T development over the last decades.

It is an important long-term policy of the Chinese government to actively promote international S&T cooperation and exchange. So far, scientific agreements have been signed with 85 countries and scientific cooperative relations established with 134 countries and regions. The government attaches great importance to the integration of scientific cooperation with economic cooperation and trade so that scientific collaboration acts as a key channel in introducing advanced technologies and funds, stimulating the trade of technologies, products and service. In order to encourage internationalization, the Chinese government is actively creating conditions for attracting overseas research institutions and enterprises to run jointly research institutions and S&T enterprises in China through joint venture and cooperation. Meanwhile, Chinese research institutions and S&T enterprises are also encouraged to establish branches abroad jointly with their foreign counterparts. In 1993 the SSTC and Ministry of Foreign Economic Relations and Trade granted 100 scientific research institutions autonomy in foreign trade.

The Chinese Academy of Sciences plays a particularly important role in scientific exchange and cooperation. Figure 3 shows the increase in the number of personnel exchanges since 1979. The CAS has signed 67 agreements at the academy level with academies, research institutions, universities and major companies from over 40 countries. Its 123 institutes have established more than 700 cooperation agreements with their counterparts in many countries. The total exchange of personnel exceeds 6 000 persons annually. Among them, 30% are for cooperative research activities. In addition, over 150 foreign scientists have been invited to be visiting professors or to hold prestigious positions at over 60 institutes, and 14 foreign scientists have been elected members of the Academy. The CAS is also actively involved in the activities of international scientific organizations: 250 of its outstanding scientists hold leading positions in international S&T organizations. It has established cooperative relations with the United Nations Development Programme (UNDP) and UNESCO, and is the national contact point of a number of international organizations such as IUCN–The World Conservation Union and the World Climate Research Programme.

Through international cooperation, R&D work has been enhanced, a large group of outstanding talents trained and a number of excellent research results have been obtained. It is hoped that with further joint efforts progress will be achieved in basic research and applied research (especially in those areas in which Chinese scientists are prominent and where there is a rich accumulation of data and experience); in research disciplines where China has its unique features (such as natural resources, environment, ecology, desert management and control and the study of natural medicinal herbs); in high technology (including information, computers, aerospace, new materials and biotechnology); and in agriculture; and that greater contributions can be made to the development of science and the progress of humankind.

FIGURE 3
INTERNATIONAL SCIENTIFIC COOPERATION SINCE 1979, AS INDICATED BY NUMBER OF CAS PERSONNEL INVOLVED IN EXCHANGE PROGRAMMES



Zhou Guangzhao is President of the Chinese Academy of Sciences. He graduated in Physics from Tsinghua University, then pursued his graduate studies at Peking University before joining its faculty in 1954. He was appointed Professor of the Institute of Theoretical Physics of the Chinese Academy of Sciences in 1979, becoming its Director in 1983. During his distinguished research career in theoretical, nuclear and high-energy physics, he has published extensively and has been accorded many honours by overseas learned societies.

After a short period as Vice-President of the Chinese Academy of Sciences Professor Zhou became its President in 1987. He is also closely associated with the work of the Pacific Science Association and the Third World Academy of Sciences, and holds high office in both organizations.

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2

CONTEMPORARY ISSUES

The ethics of science: between humanism and modernity

NOELLE LENOIR

Inherent in any review of world science today is a basic consideration of the position and responsibilities of researchers in society and, in general, of the role of science in the progress of civilization. To put the issue in other terms, a *World Science Report* cannot avoid tackling one of the crucial questions of the day: What ethics should apply to science?

In his excellent introduction to the *World Science Report 1993*, M.G.K. Menon, President of the International Council of Scientific Unions (ICSU), a renowned physicist and a serving member of the Indian parliament, raised this very issue under the heading: Ethical aspects, human rights and the public image of science. His intention was to show that scientific advances alone cannot guarantee moral progress, any more than they can strengthen or preserve human rights. This is a matter for the individual – who is responsible for, if not master of, his or her own destiny – and society as a whole. Such a proposition can however be taken further: although our well-being is largely determined by the contribution made by science and technology, everyone today is aware of the hazards to humanity of some of their applications. This century we have seen science and technology serving both good and evil. There have been prodigious medical discoveries, such as that of penicillin, and atom bombs were dropped on Hiroshima and Nagasaki; we have seen the promising first fruits of the Green Revolution, and some instances of irreversible damage caused to the environment; space has been conquered, and the precious resources of our planet pillaged.

The ethics of science certainly do not constitute a new issue. Since the dawn of time, human history has been marked by advances in knowledge, and scientific theories, having explained these advances, have always led to ethical and philosophical controversies. This is easy to understand when scientific advances surpass or even call into question the previous corpus of knowledge that had appeared to provide the final answer. But to take the matter further, it is clear that science – encompassing physics, chemistry, biology, astronomy and mathematics – continually challenges society by suggesting, usually implicitly, a particular interpretation of the universe and our place in it. There is little likelihood that a scientific answer will ever be found finally to resolve this fundamental challenge. In fact the scientific interpretation of the mechanisms of the universe will always have philosophical and political repercussions: thus the disarray caused by the Copernican Revolution and the Inquisition's trial of Galileo. With the Earth no longer the centre of the Universe but merely a simple planet in orbit around the Sun, is not the role of man – God's creation – diminished? Similarly research in biology, especially neurobiology, is raising new questions as to the specificity of *Homo sapiens* compared with other living species.

Our self-interrogation about our own condition has never, however, held us back in our continual search for knowledge. On the contrary, from the very beginning we have striven to model the world in order to adapt it to our own needs, by fighting hunger, disease and all the other forms of assault to which we are exposed. Nor shall we cease to do so.

The change in society in the light of scientific progress has essentially been one of perspective, with a growing universal awareness, particularly since the end of the Second World War, of how ambivalent this progress can be: while certainly a factor in humankind's well-being and liberation from natural constraints, it is now also regarded as a possible instrument of self-destruction.

Against this background, ethics encourage us to be continually on the alert, the aim being to ensure that science and technology make a positive contribution to the common well-being and to social and democratic progress.

Without such ethical vigilance, the public distrust of scientific and technical innovation is liable to intensify, encouraging the emergence of political and religious movements which make the rejection of modernity, held up as a symbol of the perverted contemporary world, into an item of dogma. Whereupon fear – 'humanity's most faithful companion' – leads societies into a state of tension (Bedjaoui, 1995) and, above all, prevents the creation of those international links of solidarity which are the basis of world peace and prosperity.

The ethics of science, as a process of reflecting on the consequences of progress, act in a way that questions the international community and hence the leading international organizations, including UNESCO. The triplicity that underpins UNESCO – education, science and culture – does, in fact, relate very precisely to this important ethical question: What is required of humanity, in terms of individual and collective behaviour, if it is to be capable of meeting the challenges of science and technology?

The world has become fluid and unstable and its future seems uncertain, owing not only to accelerating population growth but also to the extent of technological hazards. Hence the need for a frame of reference – in other words a system of ethics – that is compatible with awareness on the part of today's society of its responsibilities to future generations. The fact that 'what happens tomorrow is decided today' invokes more than ever an ethic of responsibility.

These responsibilities are those of every man and every woman. However, they are also the responsibilities of the scientists, because their discoveries lie at the root of the innovations that are 'changing our lives'. The time when it seemed possible to draw a clear boundary between science and technology and between research and its applications has long gone. As M.G.K. Menon points out, 'Science is no longer a stand-alone activity, at the fringes of society; but one closely intertwined with medical, industrial, agricultural and other production sectors, and with governmental and intergovernmental functioning, in such a manner and to such an extent that it pervades and affects society as a whole'. Thus the myth of the professor in the ivory tower belongs to the past. In these circumstances, two major questions must be raised:

- What special social responsibilities are incumbent on scientists?

- Is it possible to conceive an ethical scheme that will guarantee a reconciliation of technical and human progress?

THE ETHICS OF SCIENCE AND THE SOCIAL RESPONSIBILITIES OF THOSE INVOLVED IN RESEARCH

'Human beings have forgotten a great truth. But you must never forget it. You will always be responsible for that which you have tamed.' So speaks the fox to the 'Little Prince' in Saint-Exupéry's story. This epitomizes the ethical principle of responsibility, meaning that nobody, not even the researcher, can remain detached from the consequences of a development which transforms the daily life of individuals and even relationships between countries.

Although it is possible to conceive of the principle of 'responsibility' according to the collective approach as defined by the philosopher Hans Jonas, it must be accepted today that specific responsibility is incumbent on those doing the research. Their involvement in society is changing in a way which is only seemingly paradoxical. It is in fact precisely when science appears to have lost all 'teleological' ambition that research exercises a growing *de facto* influence on the course of history.

Science has lost its teleological ambition

Science alone cannot establish a global scheme for society. To put it another way, science is not direction. Three principal factors support this statement: first the growing compartmentalization of knowledge, secondly the demystification of progress as a value in itself and, finally, the secularization of science.

The compartmentalization of knowledge has steadily become more marked over the centuries. The breakdown of knowledge into increasingly specialized disciplines is the inevitable counterpart of the extension of understanding. It is probably also one of the prerequisites for research to be efficient.

At the same time, however, this 'hyperspecialization' can result in a weakening of inventive capability, since major discoveries are often the unexpected outcome of a combination of different approaches and concepts. Similarly, each discipline, closely confined within a speciality, is forced to plumb the resources of other sciences and technologies, as in the case of biology, which makes particular use of the tools of physics and chemistry, and nowadays those of robotics and computers.

By the same token, no one science can now claim to possess a unified explanation of the world. Science is no longer expected to explain everything: there has been a loss of faith in its ability to do so and to make the entire universe intelligible on the basis of a coherent order of cause and effect; indeed, ideas of instability and chaos are now at the centre of certain lines of research.

As for progress, it is no longer regarded as a source in itself of well-being for humanity. Some people see it as a neutral phenomenon. Others, who denounce the 'damage caused by progress', see it as the cause of new evils: the degradation of the environment, adverse effects on human health, the dehumanization and robotization of society, the creation of social inequalities and the enhancement of North–South disparities.

The idea that the human race may be its own predator is an old one. But today this idea is accompanied by a certain demystification of progress. It is even sometimes associated with attitudes – more or less fair and appropriate – of stigmatization towards industrialized societies.

The third important factor in the changing status of science is its secularization. As Jean-Pierre Changeux, President of the French National Ethics Consultative Committee, put it: 'the scientific approach ... is accompanied by cumulative progress in knowledge and its applications ...', science itself no longer being regarded, like law or morals, in terms of the end product of prescribing Good and condemning Evil. To use the expression of the philosopher of science, Georges Ganguilhem, quoted by Changeux, science 'constitutes truth without finality' (Changeux, 1995).

Thus it seems that science should no longer be placed in opposition to religion or morals. Its vocation, as an expression of human thought, is to point out clearly how we human beings may ensure our own survival, well-being and liberty. However, it is still up to us to identify the common values whereby these objectives might be attained. This responsibility contains at its heart that field of ethics defined as 'the theoretical study of principles, and of the set of principles, which guide human actions' (Changeux, 1995).

The impact of science on society

Scientists have become essential players in social change. Indeed, the alliance between science and technology is enhancing the impact of research on all aspects of human activity. To begin with, the technological changes induced by scientific discovery are increasingly rapid. The reason for this is that less and less time is needed between a discovery and the application of its results.

This phenomenon is particularly marked when – as in the life sciences – it is often impossible to draw a clear boundary between basic research, applied research and technological development. Medical research is a typical case: when a gene, the malformation of which is responsible for a disease, is identified, the fact is almost immediately followed by the development of the corresponding genetic test. In computing, which requires the use of mathematical models, the performance of systems is improving at such a rate that both hardware and software are permanently in a state of obsolescence. Their replacement leads of course to continual changes in methods of action and modes of thinking, and this applies to sectors of activity. 'Science is proceeding faster than humanity', to quote from the speech made by the President of the French

Republic at the establishment of the French National Ethics Consultative Committee in 1983.

Science is no longer linked only to the technological innovations it produces. Science and economics are increasingly interdependent. Indeed, the growth of the world market is dependent on the new outlets that innovation produces. Correlatively, the cost of research is steadily increasing and it is for this reason that research today needs private as well as public sources of finance. Readjustment is particularly accentuated in the medical sector. For example, to develop a new molecule in the pharmaceutical industry takes about 10 years and some US$100 million on average. This is why a concern for commercial viability is now commonplace in research circles and why research itself is the subject of fierce competition between companies and between countries.

The need to produce a return on investment puts pressure on the conduct of research. In the debate on the biotechnologies in particular, financial constraints are encouraging research laboratories to lodge patent applications at an increasingly early stage in order to secure the potential benefits of subsequent industrial applications. This is the origin of the well-known controversy on whether or not living organisms can be patented. Opponents claim that it is in any event immoral to patent species or genes which, by their very nature, should not be open to appropriation. Others merely dispute the idea of patenting the discovery of natural genes which cannot be regarded as an invention in the sense used in patent law. Yet others emphasize the fact that the question of the patenting of living organisms is an old issue and does not itself raise ethical problems, pointing out that it is also a factor in the continuation of research in biology and genetics. By ensuring payment to the 'inventor' – in reality an industrial or financial organization or government – it in fact provides some financial compensation for the earlier investment. As the European Parliament's rejection on 1 March 1995 of the proposed directive on legal protection for biotechnological inventions illustrates, this is a fundamental debate which, whatever the legislative result, gives a measure of the issues raised by science.

One of these issues also concerns the perception by public opinion of science and technology as to some extent 'hazardous' activities. The nuclear danger, both military and civil, has no doubt played a decisive role. In any event the public's increasing concern about technological hazards has now become widespread.

It cannot be denied that modern science, in giving humankind unequalled powers for changing the world, has given us at the same time an unequalled potential for destroying the planet. A particular feature of this century is society's 'vulnerability' in the face of 'technological threats'.

This process has gone so far that the scientific community feels increasingly caught up in the debate about the power of science. This feeling of responsibility on the part of researchers was reflected in the remarks made by the Nobel prizewinner, Jacques Monod, as long ago as 1970, when the techniques of genetic engineering were at a very early stage: 'Will modern societies be able indefinitely to control the fantastic powers science has given them, simply using the criterion of a vague humanism modulated by a kind of optimistic and materialistic hedonism?' asked the great biologist, adding: 'Will they be able, on this basis, to resolve their intolerable tensions? Or will they collapse?' (Russ, 1994)

THE ETHICS OF SCIENCE: A NEW HUMANISM

It is perhaps worth noting that Jacques Monod was a biologist. Indeed, it was progress in genetics which led to the appearance of the ethics movement in the 1960s. Earlier on, it is true that nuclear physics had led to bitter disputes after the dropping of the atomic bombs in 1945. At that time however no organized reaction followed, as it has in bioethics. Genetic engineering, being a process for modifying living organisms, was the subject of discussion from the outset. This fact is particularly worth noting since the first questions about the scope and hazards of the technology came from the geneticists themselves. In one way they too were present at the birth of scientific ethics in the modern sense of the term.

At a conference held at Azilomar in the USA, geneticists meeting to exchange experiences decided to declare a moratorium on their research. This was essentially a decision to mark a pause, giving time for an understanding of the possible risks to human health and the environment of using genetically modified organisms. The moratorium lasted one year. Most countries have now promulgated legislation that lays down the safety rules to be followed in cases of confined utilization or deliberate dissemination of genetically modified organisms. Moreover, it has become fairly routine to declare a moratorium on some particular research aspect or technological application. At the time of the Azilomar conference, however, such a thing was unknown. Indeed, what other technology has ever seen its applications halted at the outset by the wishes of its inventors?

Besides nuclear engineering and genetics, there is another preferred field of ethical reflection: the information technologies, which are expanding dramatically through computers, satellites and all the other modern facilities for collecting and transmitting data.

Until recently, attention has been focused primarily on the risks of infringing the privacy and individual liberty of people through the holding and use of personal data, relating in particular to their financial or family situations, health, consumer habits or opinions. This concern has led a number of countries to adopt 'data protection' legislation, and this is now backed up by international law, notably in the framework of the Council of Europe and the European Union. In the near future it will probably prove necessary to apply similar control to the use of virtual image techniques which open up completely new prospects for reconstituting and hence simulating reality.

Today there is also ethical concern about the formidable potential influence, both intellectual and moral, of audio-visual communications everywhere in the world. These techniques, as they sweep away the constraints of time and distance, are as revolutionary as the invention of printing was in its day.

Freedom of communication, when exercised with respect for pluralism and for the essential requirement for honest presentation of information, is not just an attribute of democracy, but one of its foundations. However, the development of the media carried with it two disadvantages: first the vulgarization of information; secondly – and most important – a danger of standardizing and even manipulating public opinion. Scientific work is increasingly exposed to the media and is neither more nor less exposed to these dangers than any other field. This is why researchers have the special social responsibility of communicating the results of their research to the public and making clear the real issues involved (French National Ethics Consultative Committee, 1994).

The primary duty of researchers here is to comply with the requirements of rigour and caution that underlie the dignity and nobility of their art. An elementary precondition in the professional ethics of research is for only those results which have satisfied the essential procedures of review and validation to be published. Of course, there is always a degree of temptation to publish premature or even dubious results because of the potential media and financial spin-off.

Concern for ethics, born of the growing awareness of the worldwide challenges of science, is no longer merely a theoretical movement. It is now in the process of being institutionalized through the establishment of *ad hoc* ethical authorities. Moreover, there is a detectable movement 'from ethics to law'. More and more national laws are being passed and more and more international positions are being adopted, all tending towards a redefinition of the ways in which human rights, faced with the challenges of science and technology, can be protected.

The ethics of science, scientists and society

The development of the ethics of science may be seen first as a move on the part of scientists to become more open to society. The 'Azilomar moratorium' is sometimes regarded – in view of its psychological and media impact – as one of the first signs of scientists being involved in the bioethics debate. Nevertheless, the ethical sensitivity of researchers had already found other occasions to express itself prior to 1975, and a number of more permanent initiatives reflect the scientific community's growing awareness of public concerns and aspirations.

Last century, scientists were essentially concerned with promoting their disciplines and trying to popularize them in order to obtain public support. For example, this was the reason behind the creation in 1831 of the British Association for the Advancement of Science, followed in 1848 by the establishment of a similar group in the USA.

Researchers are better organized internationally today than at national level, with objectives somewhat different from those of the 19th century scientific societies. The aim now is no longer merely to encourage the development of science and technology, but also to consider the effects of these advances on society and to make known the opinions of the scientific community on particular aspects whenever necessary.

Thus a large number of organizations for joint action and cooperation between scientists have been set up around the world. Indeed, new bodies continue to be created regularly. The list is long. Some have the status of international non-governmental organizations (NGOs), for example the International Council of Scientific Unions (ICSU) and the Council for International Organizations of Medical Sciences (CIOMS). Mention must also be made of MURS (the Universal Movement for Scientific Responsibility), directed by the Nobel Prize winner Jean Dausset, who is responsible for considerable progress in ethical thinking about science.

These organizations are valuable on two counts: first they provide a forum for multidisciplinary exchanges, which are particularly indispensable as they make it possible to cross the boundaries between the different scientific cultures. Secondly, the discussions they encompass, once they are made public, contribute to the democratization of the ethical debate.

The most original sociological phenomenon, however, is still the creation of ethics committees in an increasing number of countries. Beginning in the 1960s, these committees were set up in an almost spontaneous manner, essentially in the field of the life and health sciences, in research centres and hospitals. Their existence was then made official, and in 1983 France was the first country to establish a national consultative committee for ethics in the life and health sciences. Since then this model has provided the inspiration for other countries in Europe and subsequently elsewhere. According to the survey made in 1994 by the UNESCO Bioethics Unit, there are more than 200 national ethics committees (Kutukdjian, 1994) with various terms of reference and responsibilities.

Whatever their fields of activity, if these committees are to deserve the 'ethics' label, they must satisfy at least two conditions: they must be multidisciplinary and pluralist by involving representatives of the so-called 'exact' sciences and the human sciences, together with representatives of several currents of thought; and by statute they must be independent of the political and economic authorities, ethics being necessarily based upon the free interplay of opinions and knowledge (Ambroselli, 1990; Le Bris, 1993). The opinions and recommendations of ethics committees, whose responsibilities are usually consultative, are not intended to find definitive solutions to ethical problems. The ethics debate, by definition, is renewed and nourished by questions raised by new situations generated by science.

Again by definition, neither a committee of peers, nor a committee of experts, nor ethics committees are centres of decision making, because this is a matter for the political authorities. But ethics committees do prepare the way for the choices that have to be made. Also, one basis of their legitimacy is ensuring that the ethics debate is transparent.

The 'ethics committee' approach is no longer just a national phenomenon, and international ethics committees now exist. One of these is the European Union's advisory group on ethics in biotechnology, which reports to the Brussels Commission. Set up in 1991, it has nine members – scientists, lawyers and philosophers – from nine different countries. Its task is to identify the ethical issues raised by the technologies of living organisms, so that these questions may be incorporated into draft European Union legislation concerning the various relevant areas (agriculture, health, foodstuffs, industry, the environment, consumer protection and so on).

A second international ethics committee, and the only such worldwide body, is the International Bioethics Committee (IBC) established by UNESCO in 1992 at the initiative of the Organization's Director-General, Federico Mayor. A unique body in its field, the IBC is a forum for the exchange of ideas and information and for 'North–South' meetings. Its 50 members come from 35 countries and represent a highly diversified range of disciplines. Apart from scientists, lawyers, philosophers and sociologists, there are demographers, anthropologists, nutritionists, indeed all the specialisms related to the concerns of the countries of the South.

The IBC, unlike the EU group, does not give its views on individual topics. At each of its annual plenary meetings, held at UNESCO's Headquarters in the presence of invited members of the public and the press, the committee simply reports, with an eye to the future, on the status of genetic research around the world and its applications: genetic therapy, genetic tests, the neurosciences, genetic advice and so on.

The essential task of the IBC, however, is of a legal nature. Its terms of reference, as given to the Director-General in a resolution adopted on 15 November 1993 by the General Conference of UNESCO at its Twenty-seventh Session, envisage the 'preparation of an international instrument for the protection of the human genome'.

The ethics of science and the universal principles of human rights

The discipline of ethics, even if it does connote a continuous process of inquiry, is not limited to a single approach. Its self-selected objective, that of 'guiding human activities', necessarily leads to principles based upon the essentials of human rights:

- The first principle is the preservation – whatever the potentialities of science – of respect for the dignity of the human being, in which freedom is an essential component.

- The second key concept, based on the principle of responsibility, is the conviction that humanity must be protected from the threat of humankind itself. Seeking to minimize technological hazards becomes an ethical imperative.

- The third ethical principle concerns the links – political, economic and religious – between science and the authorities. Although scientists, in their role as experts, should not try to supplant these authorities, the latter should similarly respect and guarantee the independence of research as an instance of freedom of thought. There is a cogent case for this requirement to be formally reaffirmed, in view of the many examples in the past where these rules of conduct have been perverted. The authorities may be tempted to defend their hegemony by simply declaring that certain discoveries are null and void, like the Copernican theories condemned in 1616. Or they may wish – conversely – to exploit science to support their own ideologies, as illustrated by the peregrinations of

Soviet 'proletarian biology' under the influence of Lysenko in the 1950s.

These, then, are the three main principles that should underpin the ethics of science: respect for the dignity and freedom of the human being; containment of the technological hazards on which the future of humanity depends; preservation of the freedom of scientific creation.

Finally, it is not possible to speak of the ethics of science without mentioning a fourth essential: that of the intellectual and moral solidarity of humankind referred to in the Preamble to UNESCO's Constitution. Indeed, it would be intolerable if the advantages stemming from progress were to benefit only the richest countries or the wealthiest classes. The sharing of scientific knowledge is a prerequisite if countries are to gain access to lasting development and all people to benefit from living standards commensurate with their dignity. As the Director-General of UNESCO, Federico Mayor, pointed out in his address to the International Bioethics Committee in September 1994, '... scientific progress and knowledge are universal; as such they should be considered to be common heritage and, consequently, should be shared equally'.

It is in the field of the life sciences that ethical considerations appear to have made most progress. The science of genetics is generating much hope that this century's major diseases will be eradicated. At the same time, however, it is raising the fear that the human species and its environment may be threatened. Genetic engineering makes *Homo sapiens* the 'human engineer', to use the apt expression of Mr Bedjaoui, a member of the IBC.

This two-sided issue has led to the adoption of a great deal of legislation on the ethics of biological medicine in Europe, the USA and Latin America (Brazil). A draft framing convention on bioethics, prepared by the Council of Europe, was published at the beginning of 1994. All this legislation concerns the medical applications of biology and genetics. It is progressively being extended by laws of a more general nature on genetic research, laying down the safety rules (in the form of national regulations and European Directives) to be observed in cases of contained utilization or deliberate dissemination of genetically modified organisms.

The United Nations, for its part, has formally linked ethics to human rights. At the Vienna Conference in June 1993, the United Nations called upon states to ensure the observance of human rights and dignity in the work of the life sciences and in biological medicine. Prior to this, the United Nations had focused on the preservation of the diversity of living species by adopting the Convention on Biological Diversity of 6 June 1992 in Rio de Janeiro. The World Health Organization plans to launch an 'ethics and health' programme. Finally, the Interparliamentary Union placed the question of the links between bioethics and human rights on the agenda of its March 1995 session.

The IBC, in accordance with its terms of reference defined by UNESCO in November 1993, has been preparing the first wide-ranging international instrument on 'protection of the human genome'. The outline of a declaration drawn up in March 1993 by the Legal Commission of the IBC, presided over by Ambassador Hector Gros Espiell, is the subject of a far-reaching consultation process, on an informal basis, involving international governmental and non-governmental organizations, major universities and a large number of ethics committees. This procedure, begun in 1995, reflects the concern that the future text should be a basis for dialogue between the different cultures of the world.

However, the main contribution of the outline declaration is to place the human genome firmly in the 'common heritage of humankind', to make it – together with all the individual rights that belong to humankind – subject to international law. With this in view, the text reaffirms the rights of the individual to preserve his or her dignity and freedom. It condemns in particular any discrimination based upon genetic characteristics. Implicitly it expresses the rejection of the reductionist approach which claims to summarize a person's personality through its genetic component. We are not 'all genes', as the biologist François Gros has written.

The first international document to affirm that the human being was not a mere object for science was the Nuremberg code, drawn up in 1947 by the World Medical Association following the revelations about the 'experiments' carried out by the Nazis on human guinea-pigs. The outline similarly recalls that every individual must give consent for research to be carried out upon him or her.

The outline declaration finally sets out two other principles which stem from cultural and social rights:

- The freedom of scientific creation. This excludes in particular the situation – which would now be illusory – whereby only research apparently likely to lead to applications useful for humanity would be authorized.

- The right of everybody to benefit from advances in genetics. This right, which is far from being achieved in concrete terms, is based upon equality, which in the light of world developments is increasingly important as an objective in itself.

These different principles, the first few milestones of international ethics, can, of course, be transposed to fields other than the life sciences. After all, the subject of ethics is not in fact science as such but the human being and, beyond the individual, the human species itself.

It remains for the ethics of science to overcome inherent contradictions:

- to reconcile respect for cultural pluralism with the necessarily universal character of human rights;

- to provide modern society with the means of ensuring that the hazards of technological innovations are contained while freedom of research is guaranteed;

- to take into account the socio-economic basis of increasingly costly research, while preserving the free flow of scientific information and the dissemination of scientific culture around the world;

- to acknowledge the particular social responsibility of researchers while enshrining in law the principle of the responsibility of society as a whole.

As the French poet René Char said, 'No testament precedes our inheritance'. This is tantamount to saying that human dignity is related to our awareness of our responsibilities and that the ethics of science, which express that awareness, are one of humankind's first duties.

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Mme Lenoir has served as Chairperson of the International Bioethics Committee of UNESCO since its inception in 1993. She also chairs the European Commission's Group of Advisors on the Ethical Implications of Biotechnology. Her publications include *Aux frontières de la vie: une éthique biomédicale à la française*, published in 1991.

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Megascience

J. THOMAS RATCHFORD AND UMBERTO COLOMBO

Governments, companies and other institutions invest substantial resources in scientific research. In recent decades, this investment has increased at an exponential rate. Overall investments in research and development (R&D) range between 2% and 3% of gross domestic product (GDP) for most large, industrialized nations.

In recent years, very large research projects have taken an increasing portion of research budgets, especially governmental research budgets. This is not surprising. As we learn more about how the universe functions, nature's remaining secrets are increasingly complex, subtle and well hidden. Ever larger and more expensive research projects are required to unlock at least some of these secrets. This is not only a matter of satisfying human curiosity. The knowledge so gained may reveal solutions to some of the most pressing problems affecting humankind in future generations. Examples include the need to overcome global warming while satisfying growing energy needs, and an all-out effort to tackle the mounting problem of epidemics such as AIDS that cannot simply be checked by changes in hygiene or sanitation.

Superimposed against this background is the likelihood that scientists will face starkly reduced funds for the foreseeable future. The capital-intensive science and technology (S&T) megaprojects are particularly vulnerable. In a time of scarce resources, they are increasingly judged on their costs, on the number of jobs they might create, on their contribution to economic competitiveness and on their direct contribution to societal demands – rather than on their scientific validity. This shifting rationale may mean that, given the time-scale inherent in big science, several current megaprojects, inherited from the past 'golden age' of science, will come under ever closer scrutiny. Some policy makers are now prepared to argue that, if this means slowing the pace of scientific progress, so be it. This gives great scope for the politicization of science and for the role of lobbies – both scientific and other. In parallel, in many areas of science, national funding constraints are driving increased interest in international cooperation.

An increasing number of ever more expensive, large-scale research projects has caused divisions within the scientific community in recent years. Supporters of 'small science' have challenged big science budgets, arguing that economic benefits come more naturally from small science. Further, certain scientific disciplines such as high-energy physics and astronomy depend much more on large-scale research projects than do others such as condensed-matter physics, organic chemistry or molecular biology. This has led researchers in some fields of science to claim that big science projects are funded at their expense.

The question 'What is big science and what is small science?' is not always easy to answer. For example, megaprojects such as synchrotron light sources are used in support of small science projects carried out by large numbers of individual investigators. Should such facilities be allocated to the big science or the small science budget category?

Fundamental to the question of where the funds come from for big science projects is the concept of a 'science' or 'research' budget. Do governments have a fixed science budget? Would the funding for big science projects go instead to small science if the big science projects were cancelled?

WHAT IS MEGASCIENCE?

This chapter uses the term megascience to encompass very large, predominantly basic scientific research projects or programmes. Large technology projects, such as the space station, that are not primarily basic research efforts are not included. Since some megascience projects (megaprojects) require the development and application of very expensive and technologically sophisticated apparatus, the distinction is not always easy to draw. For example, one megaproject of a largely technological nature, the International Thermonuclear Experimental Reactor

Is there a science budget?

Many scientists firmly believe in a 'science budget', and that all research projects compete with each other for a portion of that budget. These same scientists fear that new megaprojects will take funds from other areas of science in what is essentially a zero sum game.

It is more likely that each megaproject is justified separately, with different sources of political support. Funds for megaprojects in the past have mostly not come from existing R&D budgets, but have been add-ons. When megaprojects have been cancelled before completion, such as in 1994 with the Superconducting Super Collider (SSC) in the USA, the unspent funds were lost to research.

Hubert Curien, President of the CERN Council and former Minister of Science in France, summed up this point of view at a 1994 conference on large facilities in physics. He said: 'Some scientists naturally think that with the same money one could do many other things. The problem is that one will never have the same money; if money is not spent in one field in science, there is no hope of transferring it to another.'

The important question is whether the future will be like the past. The answer is not clear, since governments face budget pressures unlike any faced for at least two generations. International cooperation in megascience may, in fact, be seen as a way of rationing funds for big science projects in a period of austerity.

(ITER), is on the borderline between technology and science, since scientific evidence for the feasibility of controlled and sustained thermonuclear fusion has yet to be demonstrated. ITER links the world's four major thermonuclear research efforts – the USA and Canada, the European Union, Japan and Russia.

Megascience in this chapter does not refer necessarily to large, integrated laboratories such as Brookhaven National Laboratory or one of the Max-Planck Institutes. The scale of research in these laboratories is certainly equal to that of many megaprojects; however, they lack the coherence and single-minded objectives of true megaprojects.

We shall refer to two fundamentally different types of megaprojects:

- the central facility megaproject, such as the space telescope and the European Synchrotron Radiation Facility;
- the distributed facility megaproject, such as the various interconnected Global Change Research Programmes coordinated by the International Group of Funding Agencies for Global Change Research (IGFA), and the Human Genome Project.

Central facility megaprojects

Central facility megaprojects are easy to understand. They can be identified by geographical location and represent a substantial capital investment. Space-based facilities have obvious differences regarding location, but the principle is the same.

These central facility megaprojects may be devoted to a particular experiment or family of experiments in a narrow discipline, as one finds with a particle accelerator. Conversely, central facility megaprojects may consist of special apparatus such as synchrotron light sources and/or neutron sources used widely by researchers in traditional small science fields such as condensed-matter physics and in other disciplines such as chemistry and the medical sciences.

Distributed facility megaprojects

As the name implies, distributed facility megaprojects are not associated with a particular geographical location. Scientists in many institutions and places participate, and funding often comes from a variety of sources. There may be researchers from many fields of science, as one finds in the various Global Change Research Programmes.

How is a distributed facility megaproject distinguished from the collection of research in a field or subfield of science? First, there is a focus for the research, with some scientific or societal objective. Examples are characterizing the human genome or the measurement

Data

Data are the glue that holds distributed megaprojects together, and an ever-increasing component of such efforts, sometimes measured in terabytes. Effective data collection, management, evaluation and distribution are crucial to the success of such megaprojects. Challenges for the future include standardization and quality control for the data collected and processed, and assurance of access for qualified researchers worldwide.

and understanding of global climate change. Further, there is usually one or more coordinating group for the research. These coordinating groups can be governmental or not and can encompass both scientific and funding issues. Many, if not most, of the distributed megaprojects also have a need for some centralized data management capability, so the results of the diverse experiments are efficiently collected, archived and made available to the scientific and policy communities worldwide.

It is not always easy to categorize megaprojects as being either of the central or distributed facility type. Oceanography is usually considered in the latter category, although drilling ships are now beginning to look more like megascience facilities as costs escalate for succeeding generations of vessels. And even particle accelerators, perhaps the purest of central facility megaprojects, have a substantial portion of their costs carried by a diverse and often international cadre of users, who actually do the experiments and furnish much of their experimental apparatus.

THE GROWTH OF MEGASCIENCE

Megascience is not entirely a modern phenomenon. In the 16th century, Tycho Brahe's great astronomical observatory, funded by the Danish monarchy, was a scientific megaproject of its day. The investment certainly paid off, though not necessarily for the Danish monarchy. The work of Brahe's assistant, Johannes Kepler, underpinned the development of the Newtonian worldview which was to dominate science for over 300 years.

In the USA, perhaps the most successful early megascience project was the Lewis and Clark expedition in the early 19th century. Over 100 years later, Ernest Lawrence conceived of a machine that would split atoms and probe the nucleus. Lawrence's cyclotron was, for its time, also an effective consumer of capital and operating funds.

It was the Second World War that not only altered the relationship between government and science, but also provided the resources for a true megaproject. Although one may quibble over whether it was a science project or a technology project, the Manhattan Project certainly did push back the frontiers of basic science. And its magnitude was unprecedented: a cost of US$2 billion, compared to total US federal expenditure in 1940 for all R&D of about US$70 million.

Measuring megascience

There are no commonly accepted accounting rules for measuring the costs of megaprojects or, for that matter, of identifying a minimum level of funding required to earn the label 'megaproject'. There are a number of considerations, such as absolute cost, cost relative to total government funding of all civil R&D or of the total budget of the scientific discipline in which the megaproject is found. The unusually high cost of megaprojects constitutes an insurmountable barrier for smaller countries to undertake on a national basis. But, increasingly, even the larger nations are finding it difficult to take on megaprojects without international cooperation (see section entitled Internationalizing megascience).

Many believe that funding for megaprojects has been increasing faster than for research overall. Studies of the funding of megaprojects in the USA by the Congressional Budget Office and the General

Accounting Office in 1992, for example, concluded that megaprojects were squeezing research dollars for other areas of research. This conclusion, however, assumes the research budget is fixed, with the ability to transfer funds from one project or field of science to another. This is probably not the case (see box).

How much of the total research budget goes to megaprojects? An analysis of the US research budget by the Congressional Research Service (CRS) shows megaprojects consuming about 10% of the total federal R&D budget for the fiscal years 1991-95. Although the definitions of megaprojects are somewhat different from those used by the authors of this chapter, the comparison is useful in estimating the impact of megaprojects on research budgets. If one examines the seven civilian megaprojects identified by CRS, and compares their budgets to the total federal basic research budget, the proportion is of the order of 15%. A reasonable estimate therefore is that megaprojects consume between 10% and 20% of the US federal research budget.

WHY GOVERNMENTS SUPPORT MEGAPROJECTS

Governments support megaprojects for a variety of reasons. In the distant past the whims of emperors and kings were important. Mercantilist economies drove geographical exploration and scientific expeditions. In more recent years, national security considerations have been paramount, at least up to the end of the Cold War. Scientific fashions, however, are still very much with us today. Fashion may no longer work its effect on the climate of opinion in Versailles or Vienna, but it still helps explain the rush to fund certain areas which happen to be championed by the media. The power of lobbyists in pressing for the funding of certain causes can sometimes outweigh any rational scientific justification for the high priority assigned. Similarly, changes in fashion can suddenly alter previously accepted notions of utility of megaprojects, leading to a contraction of their budgets, as has occurred with space research.

Today, arguments for supporting megaprojects usually originate in the sub-discipline involved, and are based on scientific considerations. 'National prestige', political and economic reasons are often invoked to buttress the scientific rationale. Economic arguments range from the short term (direct expenditures) to the long range (strengthening education, high-technology industries and international economic competitiveness).

Megascience clearly augments the world's storehouse of knowledge, and provides associated intellectual, educational and broad economic benefits. Academic studies indicate that the likely social rate of return from research such as this is high. But the long-term benefits are likely to be global, not local or national, as we saw with Brahe's observatory. 'Private', or even 'national' long-range benefits are harder to identify and, when they are identified, more often than not turn out to be indirect benefits such as those related to education.

Role of scientists

As one would expect, the most likely supporters of a megaproject are the scientists working in the affected field of research. Proposals for new megaprojects originate with the scientists, usually formal or informal groups outside governments. They address the most exciting scientific challenges in the particular field. In some cases they emerge from efforts to prioritize fields of research sponsored by prestigious scientific organizations. Some of these groups are international, and various national initiatives may be included in the proposals. Some proposals originate in international institutions that would be responsible for the megaproject.

There is no rigid formula for obtaining support for a potential megaproject. The most common path is for the interested group of scientists to present its ideas to the national research agency that is the major source of funding for the affected field of research. There may be initial funding provided for a feasibility study.

Crucial to a decision to go forward are cost estimates and selection of the site and/or contractor. The decision is made by the agency, and in the case of truly large megaprojects (budgets constituting a significant portion of the agency's total R&D budget for the scientific field containing the megaproject), approved at higher levels of government. Low estimates of construction costs are not uncommon. This approach is sometimes referred to as 'the camel's nose under the tent' strategy. The excessive, and sometimes partisan, optimism of supporters may carry initial approval of a particular megaproject. But an accumulation of cost overruns and construction delays soon becomes a boomerang which, in turn, casts doubt on the credibility of future projects, even in other areas of science. This problem is compounded by the fact that megaprojects, once budgeted, are difficult to stop. Any such decision is taken with much anguish and pain.

Scientists in recent years have moved beyond the walls of the scientific community and the affected research agencies in supporting specific megaprojects. In the USA, lobbying of Congress and mounting aggressive public relations efforts are not unknown. Elsewhere, the situation is not much better. In Japan, and in Europe, lobbies supporting particular high-budget megaprojects may prevail over the concerned opinion of decision makers, as well as the majority of scientists active in the field.

Changing national attitudes

Megaprojects have traditionally been national initiatives. Information on planned megaprojects has been widely available, and the total cost of megaprojects has been shared as different nations or groups of nations funded their own initiatives. The rules of access by scientists to the facilities have in general been merit-based, with users only paying the costs of their experiments. Little geographic discrimination has been in evidence.

This situation is changing. The fundamental reasons for change are several. They include the twin realities of escalating megaproject costs and static or declining governmental R&D budgets. Public attitudes towards science and research in general are less supportive. There is growing recognition of the difficulties sponsoring nations have in capturing the long-term benefits of megaprojects. And the end of the Cold War has altered the international R&D equation, reducing the effectiveness of security-based arguments in support of national scientific preeminence. At the same time the climate is more favourable to open access, especially when the facility is not used at full capacity. Finally, economic pragmatism has undermined the effectiveness of the national prestige argument.

INTERNATIONALIZING MEGASCIENCE

For centuries, science and research have been perhaps the most international of all human activities. It is common for scientists in universities and other research institutions to have much closer collaboration with colleagues half way around the world than with those half way down the hall.

This ease of collaboration irrespective of geography has become much easier and less expensive in recent years, especially since the Second World War, because of developments in technology. Communications are instantaneous and almost free. Travel is fast and less expensive, and red tape is not nearly as complicated as it once was. One could argue that the environment for internationalizing research is in place, and that the invisible hand of the market optimizes cooperative research activities.

Current trends and political climate

There is evidence of increased cooperation in research across national boundaries, in both big and small science. There have been increases in the number of bilateral science and technology agreements between nations. Shared authorship of journal articles by scientists of different countries is growing. Many

CERN: a model for the future?

The idea of a European Centre for Nuclear Research (CERN) was launched in 1949 by Louis de Broglie, one of the early pioneers in quantum mechanics. Promptly sustained by scientific leaders such as Pierre Auger, Edoardo Amaldi and Francis Perrin, the idea was adopted as a UNESCO project proposed by Isidor Rabi and led to the signature of the convention for the establishment of CERN in Paris in 1953. CERN came into existence by treaty in 1954, resulting in the construction of a laboratory in Meyrin, near Geneva.

In its 40 years of existence, CERN has expanded from 9 to 19 member states (CERN has almost 3 000 staff and hosts nearly 6 000 research scientists per year coming from hundreds of universities and research institutes spread all over the world, participating in experiments the largest of which bring together 400-500 scientists each). Its annual budget of almost 1 billion Swiss Francs is divided among its member nations generally in proportion to their gross national product (GNP).

Four Nobel Prizes have been earned in the last decade, and five Nobel laureates are active on the site. The CERN research programme has evolved through a number of high-energy 'machines'. Presently, the Large Hadron Collider (LHC) project, an alternative to the cancelled SSC in the USA, is just getting under way.

CERN is unique in that it has long-term, stable funding under a credible treaty agreement. The question it faces is how best to allocate the research funds among competing projects, not the size of the CERN budget as a whole.

specialized agencies have arisen to facilitate international cooperation in research, several of them in the United Nations system; in particular, the role of UNESCO in developing scientific cooperation worldwide has been highly meritorious. And cooperative agreements between universities and scientific and engineering societies in different countries are increasing.

Although hard budget figures are difficult to come by, most observers believe that cooperation in megascience is increasing faster than is the case for research overall. Europe is clearly in the lead, compared with North America and Japan. Cooperation in science in Europe was already favoured by the number of relatively small players, and the progressive efforts being made to achieve economic and then political union with the foundation of the European Community. A number of intergovernmental organizations, such as the European Centre for Nuclear Research (CERN), the European Southern Observatory (ESO) and the European Synchrotron Radiation Facility (ESRF), now play major roles in European – and global – megascience.

If we exclude the decisive contribution of scientists from overseas to the Manhattan Project, the USA, like Japan and Russia, has come to international cooperation in megascience more recently. In part this was due to the scale of US research budgets and the megaprojects they funded. The USA and the then Soviet Union, fuelled by imperatives of the Cold War, unilaterally initiated many megascience projects with the explicit objective of outdistancing the other. Japan, with relatively low government funding for research and a tradition of emphasis on economically relevant research, has only recently entered the megascience arena.

The end of the Cold War has also seen changes in the political climate for megascience. This has been most pronounced in the USA, where competition with the former Soviet Union was a powerful argument for the funding of national cutting-edge megaprojects. Now it is coming to be appreciated in Congress and the White House that many megaprojects are too expensive for US research budgets, and that the only alternative is shared funding. Ironically, the statement of this principle by the US government (but not necessarily its execution) was most forthright with respect to the SSC. Europe and Japan, unlike the USA, have had fewer problems in the past with the principle of shared funding of megaprojects. One difficulty likely to hamper further internationalization is the complexity of the US budgetary process, which makes it difficult to guarantee a commitment in long-term funding to joint efforts. The reputation of the USA as 'an unreliable partner' will continue to complicate international discussions related to cooperation in megascience.

The politics among the scientific communities of the world are, if anything, more complex than in the broader society. Experts in sub-fields of research who propose megaprojects generally want them as national projects. This is because the roles for themselves as national disciplinary leaders are likely to be more prominent; in the aspiration for Nobel Prizes, national megaprojects are an asset for the host nation's scientists.

Advantages and disadvantages

There are, not surprisingly, both advantages and disadvantages to internationalizing megaprojects. There may be greater stability in funding and economies of scale if limited resources from national programmes are combined in an international megaproject. A global intellectual pool should be stronger than competing national ones. And in the post-Cold War world, political arguments for pooling resources to increase the storehouse of knowledge for all humankind is an attractive one. Furthermore, wide internationalization of megaprojects would allow them to profit from the scientific talent available in smaller countries and in developing countries, broadening also the context within which decisions are taken. An added advantage of this wider scientific cooperation is represented by the process of knowledge transfer and training-in-research that is implicit in such activity.

Internationalizing megaprojects has disadvantages as well. First, if a specific megaproject is internationally managed, there are likely to be complex governance and administrative structures that have less efficiency than national structures. International bureaucracies are particularly expensive and difficult to manage efficiently. Although needless competition may be bad, competition can also encourage innovation and efficiency.

The generally successful efforts to internationalize megaprojects in Europe have brought with them certain inefficiencies, largely associated with siting, contracting and other allocations of the economic benefits between the supporting nations. In this, however, they are not alone, as recent US experience shows. In terms of successful internationalization in Europe, such as CERN for example, the add-on overhead is generally more than compensated for by the added value accruing from the pooling of resources and broader representation of the team.

Internationalizing megaprojects need not imply that each individual megaproject be run as an international activity. Another approach is to divide responsibility for construction and management of individual megaprojects between nations, according to some fair and agreed-upon formula, with reciprocal rights of access. Some elements of this approach have been used in the past, but more recently emphasis has been given to the *quid pro quo* involved.

Currently, governments and research managers in agencies that support research see another advantage in internationalizing megascience: international agreements for the support of a specific research initiative can be useful as a budget control device. This approach is to set the level of effort for a particular megaproject or family of megaprojects politically, and to leave to the scientists the task of deciding on the specific allocation of the funds. CERN is a good example of this approach by the Europeans.

THE FUTURE

Although the past is always helpful in providing insights into the future, in the case of internationalizing megaprojects it is likely that the future will be very different from the situation since the 1960s.

While financial constraints are the major driving force favouring international cooperation, they are not the only motive.

Global problems

In today's world we are facing a host of global problems which truly can only be solved through concerted efforts to find global solutions. Clear examples come from the environmental sciences. First and foremost are studies into climate change and the depletion of the ozone layer in the upper atmosphere, but there are also joint programmes in deep drilling and oceanography. Megaprojects are underway to address some of these concerns. In the key area of world nutrition, however, much remains to be done.

Agricultural productivity growth in South and South-East Asia has begun to peak. With rapid population growth the need for food often submerges the call for environmental sustainability. Past scientific successes, principally the Green Revolution of the 1960s and 1970s, are showing their limits. There is clearly a need for more sustainable approaches which must still be developed. We have to prepare for a world with 10-12 billion human beings, of whom fewer than 2 billion will be in the rich North. Megascience could offer a hope of avoiding catastrophe. Concerted international cooperation in targeted (distributed) megaprojects uniting the latest scientific advances, specifically in the nascent field of agro-biotechnologies, pooling resources and especially sharing risks, tasks and information and data, could bring solutions much closer.

This is an area in which the commitment of individual scientists will be as important as that of governments and international organizations. Through the agencies of e-mail and the Internet, for example, team building comes about through the electronic notice board, not through negotiation. This practice is surely destined to spread and to affect big science. It may be that future megaprojects for solving global problems will first be conceived in this way.

ITER

The original idea of jointly designing and building the first thermonuclear reactor was put forward in several summit meetings, starting with the Mitterrand/Gorbachev meeting in Paris in 1985.

The ongoing quadripartite (European Union, Japan, Russia and the USA) cooperation on an International Thermonuclear Experimental Reactor (ITER), undertaken under the auspices of the International Atomic Energy Agency (IAEA), is a unique example of world collaboration in big science. Its aim is to produce by July 1998 the detailed engineering design of the reactor, and to share the supporting R&D jointly. Switzerland is fully associated with the European Union, Canada is involved in the US contribution and Kazakhstan with the Russian.

The overall programme objective of ITER is to demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes. The ITER engineering design activities are expected to cost about US$1.2 billion (shared equally), to last six years and to provide a sound basis for the decision on ITER construction. The design proper is being undertaken by a joint team of over 200 professionals and four home teams. Joint team centres are located in Japan, the USA and Germany. Supporting R&D tasks are shared equally between the four parties.

A new agreement will be necessary for the construction phase. The site selection will be particularly challenging. Construction could start in 1998, would take about eight years and cost about US$6.5 billion. ITER would operate for about 20 years.

New boundary conditions

The boundary conditions shaping the future are likely to be several, including:

- increased opportunities for scientific progress through megaprojects;
- severe constraints on national R&D budgets;
- intense competition for R&D funds, within fields and between fields of research;

- erosion of public support for basic research;
- strong pressures to 'ration' funds for megascience;
- a more aggressive role for government R&D officials.

There are already international organizations interested in coordinating and managing megascience. These include the United Nations (in particular, within the system, UNESCO, which, as we have seen, played a pivotal role in the creation of CERN and is responsible for several global research programmes), the OECD (see box) and the European Union; the G-7 has dabbled around the edges. Currently, the European Commission is a major provider of funding. Other regional bodies may also intervene. The various United Nations agencies have some experience in management of particular research areas, but little in the field of megascience. It is unclear whether these agencies working together, or another created *ad hoc*, would be able to ensure the long-term commitment of resources that is required. But the nature of the global problems which need to be tackled in an international effort could justify a special initiative on their part. On the other hand, OECD, whose current structure fits ill with the needs of research policy management, may be a possible basis on which to build a clearing-house function, coordinating funding from the world's richer countries in a shared effort to benefit all mankind. From being inevitably categorized as Utopian only a few years ago, this concept is now one to which thought is being given by all who value the contribution that global science projects can make to the future of the world.

Policy options

What might the future for megascience look like? What innovations in decision making, organization, funding and administration will evolve? The answers are not easy to ascertain, but the three different scenarios outlined below may provide some insights.

OECD Megascience Forum

The Organisation for Economic Co-operation and Development (OECD) Council established the OECD Megascience Forum on 1 June 1992 for a three-year period. Its concept and proposal was the major accomplishment of the March 1992 OECD science ministerial meeting. The Forum is an activity of the OECD Committee for Scientific and Technological Policy (CSTP).

Its function is to provide a mechanism for the development and exchange of information and studies on science megaprojects. Under its auspices a number of meetings of experts have been convened to assess the state of research and international cooperation in various megascience fields, including deep drilling, global change, particle physics and neutron beams and synchrotron radiation sources. Several reports have been published.

The Forum was never designed to be a decision-making body. However, the September 1995 OECD science ministerial meeting endorsed a proposal to extend it for another three years under a revised mandate. The Forum, composed of policy-level government officials, will continue to consider generic policy issues. Additionally, it is now empowered to create working groups of government officials and non-government scientists in specific disciplinary areas that should, at a minimum, provide closer coordination of the actions of national funding agencies in the prescribed areas. It is possible that this second round of OECD involvement in the megascience issue will lead to international agreement on a more robust and permanent framework of cooperation, such as those discussed in the section entitled The future.

Status quo

The future may look somewhat like the recent past, with strong competition between and among national scientific groups, further politicization of the funding process and erratic decision making at the national level. Given the boundary conditions noted above, this scenario does not augur well for the health of world science.

Increased project-by-project cooperation

The informal nature of cooperation in megaprojects would continue, with increased pressure from governments, enhanced information exchange capability and more widely available negotiating fora. One outcome might be the development of a *pro forma* megascience budget, with division of megaprojects between nations on an equitable basis. Problems include defining the roles of small nations and the lack of credible budget discipline for the individual countries.

Treaty or other durable agreement

Megascience projects, or at least the central facility ones, would be funded under an agreement between the nations with the largest economies. There would be a trade-off as far as the interested components of the scientific community are concerned, between stable funding on the one hand and a *de facto* rationing of resources on the other. Such an umbrella agreement or 'package deal' would be difficult to fashion. It would have to provide for the fair sharing of the benefits of megaprojects, both the scientific and direct economic benefits. It could incorporate the principle of a 'market basket' of megaprojects, some of which would be national projects for which the funding nation would receive 'credit'. The largest might be truly international, with joint funding and management.

Challenge to scientists and governments

The challenge to governments and scientists is to craft a resilient, credible, international framework for the support of megascience in the future. It must reflect current, universal budget stringencies, yet be attuned both to the real problems of the global society and to the most exciting, unsolved scientific challenges. Scientific excellence must be guarded. Equity among nations should apply both to costs and benefits. The challenge is great, but the reward is worth the effort.

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Before his move to George Mason University in 1993, he was Associate Director for Policy and International Affairs at the White House Office of Science and Technology Policy. In this capacity he developed initiatives aimed to increase international cooperation in science and technology, one of which led to the establishment of the OECD Megascience Forum.

Umberto Colombo is a physical chemist by training, carrying out several years of research with the Montedison Company in Italy before becoming, in 1971, its Director-General for Research and Corporate Strategies. Between 1979 and 1993 he occupied the posts of Chairman of, successively, the Italian Atomic Energy Commission, the Italian National Hydrocarbons Trust (ENI) and the Italian National Agency for New Technology, Energy and the Environment (ENEA). In 1993-94 he was Minister of Universities and Scientific and Technological Research in the Italian government. Amongst the many other important posts that Professor Colombo has held during the course of his distinguished scientific career are President of the European Science Foundation (1991-93), Member of the Council of the United Nations University and Member of the Executive Board of the Club of Rome.

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Geoscience and the environment: understanding human impacts on natural processes

ANTONY R. BERGER

An understanding of the geological processes that affect the Earth's surface in the short to medium term is important for many reasons. It provides ways to assess opportunities for, and limitations on, land use. It forms an essential part of the background to decisions affecting the environment, and contributes to a long-term approach to a sustainable future. It helps to identify opportunities for environmental protection and repair and leads to an appreciation of the increasing impact of environmental factors on business decisions. Geoscience (or more traditionally geology – the study of the Earth and the physical materials from which it is built) provides an insight into the physical setting, causes and effects of natural processes and human activities, improves environmental awareness and fosters a capacity for stewardship.

Environmental problems, challenges and issues are widespread. Population pressure and poor planning have commonly turned minor problems for small groups into potential or actual catastrophes for large numbers of people. Though such natural processes as river and coastal erosion, landsliding, volcanism and earthquakes cannot be switched off, geoscience helps to improve the planning, development and management of human communities and to warn of impending natural disasters.

The environment is the entire web of the geological and biological interactions that determine the relationship between life and the planet Earth. There are different views of the scope of the relatively new field of environmental geoscience. In North America and Europe, where industrial and urban clean-ups employ a growing number of geologists, a major focus is on detailed investigations of point-source pollution and waste sites, applying such techniques as those of hydrogeology and geophysics to the identification of sub-surface conditions.

A broader view regards environmental geoscience as the study of those aspects of the physical environment affecting or influenced by human activity and Earth processes. Among the contributions to society are:

- finding and helping to develop sources of groundwater for domestic, industrial and agricultural use;
- determining the natural levels of toxic elements in soils, water and sediments so as to establish standards for pollution control and monitoring;
- helping to clean organic pollutants from aquifers;
- identifying stable sites for engineering works or waste disposal, avoiding leakage, collapse or subsidence;
- studying volcanoes and seismicity in order to understand the risks and to warn of impending eruptions and earthquakes;
- advising on building codes that prevent development of unstable or hazardous areas;
- minimizing harm to the environment while exploring for and extracting minerals and fossil fuels;
- mapping and regulating onshore, coastal and offshore areas for waste disposal, pipeline and cable routes, and oil and gas production facilities;
- understanding the record of climatic and other changes in the environment, especially over recent centuries.

Geoscientists are concerned with a broad range of environmental problems. Farmers and rural dwellers in many parts of Asia, Europe and North America have to cope with the contamination of water supplies by fertilizers and soil additives, and the pollution of the air by industries such as chemical manufacturing, coal, smelting and refining. The extent of soil and water contamination in the former Soviet Union from the disposal of toxic wastes is just now coming to light. Indeed, 'chemical time bombs' may result when harmful wastes accumulating in otherwise stable places in soils or sediments are suddenly released because of the lowering of the groundwater table, accelerated erosion, or melting of frozen soils.

Many coastal communities must cope with the threat of inundation from rising sea level or of shoreline erosion, whether in island states of the Pacific, or the southeastern USA. City dwellers around the world have concerns about waste disposal and access to clean water and air. In many crowded megacities, especially in developing countries, residents face life-threatening water shortages, unstable ground conditions, or even destruction by powerful earthquakes, in part because of poor construction codes and inadequate housing.

Environmental problems are commonly described as if they occur in isolation, with the implication that they can all be readily managed, for example by standard engineering approaches. Geoscience increasingly takes the view that the Earth is an integrated system, and that one event or process affects another, sometimes with a ripple effect throughout the whole system. Thus, volcanic emissions to the stratosphere may influence the global climate, the chemistry of surface water and even the diversity of animal and plant life.

GEOLOGICAL PROBLEMS OF CITIES

Before 1900, no city of 5 million people existed. In 1950, there were six such cities, and the United Nations predicts that by the year 2000 there will be 60, the fastest growing of which will be in developing countries. About half the world population of 7 billion people will then be living in urban areas. The tremendous impact of human activities in these cities changes the physical environment, in many cases putting it badly 'out of balance' with nature.

City authorities are gradually recognizing the

Photo: Antony R. Berger

FIGURE 1
SUBSIDENCE AND FLOODING
In Bangkok the land surface subsided up to 74 cm between 1978 and 1987 due to rapid and uncontrolled groundwater pumping. As a result suburbs near the Gulf of Thailand are often flooded – for 22 days in one recent month – and Bangkok itself was under water continuously for four months in 1983. Flood control measures have been installed but the land is still subsiding over a 4 000 km² area.

importance of applying geology to urban problems such as waste disposal and construction on unstable slopes (e.g. ESCAP, 1988; Nuhfer *et al.*, 1993). Cities such as Caracas suffer from landslides and other mass movements due to extensive construction on unstable slopes. Others, like Hong Kong, have largely reduced what was once an expensive and dangerous geological hazard by developing sound regulations and practices for building on steep and deeply weathered slopes. The safe disposal of urban and industrial waste is a major problem around the world, for there is a shortage of unused space where garbage will not contaminate soil or water supplies. Jakarta, Mexico City and São Paulo are but three cities where drinking supplies face contamination from industrial and domestic waste.

Many cities have grown so fast that sand, gravel and other earth materials for construction have to be transported from great distances, because local resources have been built over and 'sterilized'. Extensive pumping of groundwater may cause the land to subside, leading to the flooding of such coastal cities as Shanghai and Bangkok (Figure 1).

On a local scale, measures can be taken to mitigate these problems. Groundwater pumping can be regulated, wastes can be contained and sealed from leakage, and sub-surface conditions can be mapped using modern geophysical techniques. First, however, the potential dangers must be identified, and then an inventory of all geological data must be assembled so as to pin-point areas where information is lacking. At that stage, appropriate expertise can be found and mobilized. In carrying out remedial work, close cooperation is required between those in charge of municipal policies and the scientists and engineers whose task it is to gauge the magnitude of the problem, to identify causes and to find solutions. It is not easy, for example, to gain control over a situation where individuals are permitted to sink a well wherever they wish and to pump at rates that ignore the needs of others nearby.

ENVIRONMENTAL GEOCHEMISTRY AND HEALTH

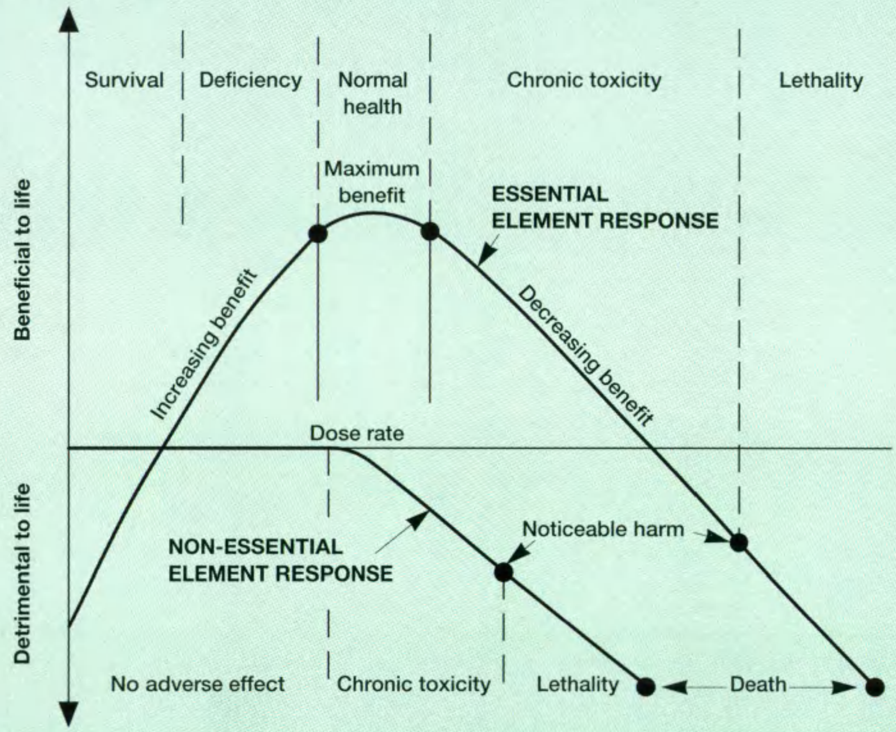
As environmental pollution becomes more widespread, it is increasingly important to detect and understand variations, especially excesses and deficiencies, in the chemistry of rocks, soils and waters that can affect human health (Låg, 1990; Nash and McCall, 1994). Geochemistry assists health and environmental managers by helping to:

- assess risks from exposure to background chemistry;
- determine the magnitude of remedial actions;
- design health education programmes;
- define areas for further environmental studies;
- predict possible effects on human health of particular elements and compounds in areas not yet surveyed.

Many elements and compounds that are essential to health are toxic when present above certain threshold values (Figure 2). As Paracelsus put it, 'All substances are poisons; there is none which is not a poison. The right dose differentiates a poison and a remedy.' For example, it is well known that the lack of fluoride in drinking water causes tooth decay, yet concentrations over 1.5 mg/l in drinking water can also cause dental fluorosis (mottling of teeth). Other examples of chronic diseases and disorders caused by deficiencies or excesses in certain elements are given in Figure 3.

Systematic and carefully controlled geochemical surveys of groundwater, stream and lake waters and sediments, soils and bedrock can identify areas characterized by toxic or deficient amounts of important elements (Darnley *et al.*, 1995). For example, medical evidence suggests that hard waters may offer some protection from heart disease and that people ingesting soft waters may have a slightly higher risk of cardiovascular disease. Maps of the distribution

FIGURE 2
CHEMICALS AND HEALTH



Schematic illustration of the benefits (e.g. low morbidity, freedom from diseases and disorders) and detriments (diseases and disorders) to human health of ingested chemicals, based on dose per unit time (normally 24 hours).

Source: Boyle, D.R., *Geological Survey of Canada*.

of hardness of surface and groundwaters can thus be used by medical authorities in designing further studies.

Though it may have little immediate effect on the quality of drinking water supplies, acid precipitation due to emissions from transportation and industrial sources can eventually modify the quality of groundwater by increasing its acidity, which can lead in turn to increased dissolution and mobility of toxic metals such as lead, cadmium, arsenic, copper and aluminium. Contour maps of the pH of groundwaters can be used to outline areas sensitive to acid rain loading and to determine the proportion of the overall population at risk.

Analysis of the pathways taken by essential or potentially toxic elements before they are ingested is another important aspect of environmental geochemistry. For example, as mercury moves through the food chain it may form highly toxic, methylated organic compounds, which become more concentrated and endanger human health. An understanding of how elements derived from bedrock and soils are cycled in nature is critical to environmental planning and management.

Techniques for extremely detailed chemical analysis have become so refined that contaminant levels in the parts-per-trillion range can now be detected in water,

FIGURE 3

TOO LITTLE, TOO MUCH: CHRONIC DISEASES AND DISORDERS CAUSED BY DEFICIENCIES OR EXCESSES IN CERTAIN ELEMENTS

DEFICIENCIES IN

Iodine → goitre, cretinism, hypothyroidism
Iron → anaemia
Calcium, magnesium, sodium → cardiovascular disease, hypocalcaemia
Chromium → diabetes, glucose regulation
Cobalt → pernicious anaemia
Zinc → enzyme-related disorders, perikeratosis, impaired wound healing
Fluorine → dental caries, ?osteoporosis
Selenium → cardiomyopathy, cancer prevention

OVER ABUNDANCES IN

Cadmium → renal dysfunction, hypertension, heart disease
Lead → neuropathy, psychotic disorders, hypertension
Mercury → neuropathy
Arsenic → cancer
Radioactive elements → cancer

Source: Boyle, 1991.

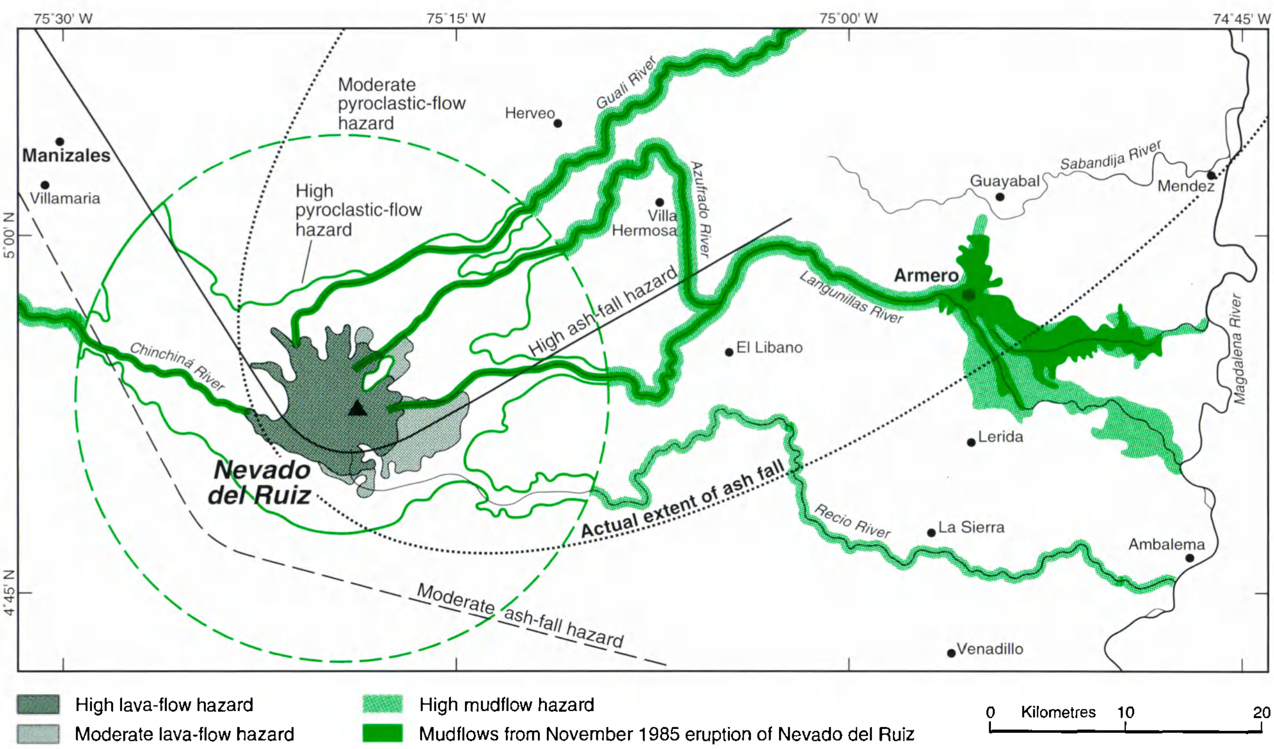
air and soil samples. However, the costs of mitigation commonly rise almost exponentially as the levels of detection increase from percentages (parts per hundred) to ppm (parts per million) levels, and the cut-off levels for sustainable environments are not known. Some citizens demand absolutely zero contamination levels, but for the most part science does not yet understand how exceedingly small amounts affect ecosystems or human life, or how they compare with the natural fluxes of the planet.

DEALING WITH EARTHQUAKES AND VOLCANIC ERUPTIONS

A great deal of knowledge and expertise is available for the prevention and mitigation of the effects of sudden, and commonly disastrous, geological events such as landslides, earthquakes and volcanic eruptions (McCall *et al.*, 1992; Nuhfer *et al.*, 1993). In the event of an actual or impending disaster, the important information must not only be readily accessible but also transmitted with speed and reliability in order to have an immediate impact in predicting hazards (events or processes that are potentially destructive) and risks (the magnitude of potential loss of life, property or productive capacity within the hazardous area).

Geophysicists and others concerned with seismic risks monitor ground motion and study deep earth structures, earthquake sources and surface effects, collecting data on past earthquakes and neotectonic activity. Researchers in the USA, Japan, Russia and elsewhere have made much progress in defining areas of major earthquake risk. Seismic gaps (apparently stable areas along known fault lines) have been identified, for example along the densely populated coastline of southern British Columbia, where the Juan de Fuca plate plunges beneath the North American plate along a major shallow subduction zone identified by deep seismic profiling. Further understanding of the historical frequency of earthquakes here and elsewhere is now coming from detailed studies of the effects of past seismicity in Quaternary sediments, in which the traces of ancient faults can be mapped and dated.

FIGURE 4
HAZARD ZONATION



Map showing volcanic hazards and risks anticipated from Nevado del Ruíz, Colombia, and circulated one month prior to the 13 November 1985 eruption and mudflow which buried the town of Armero.

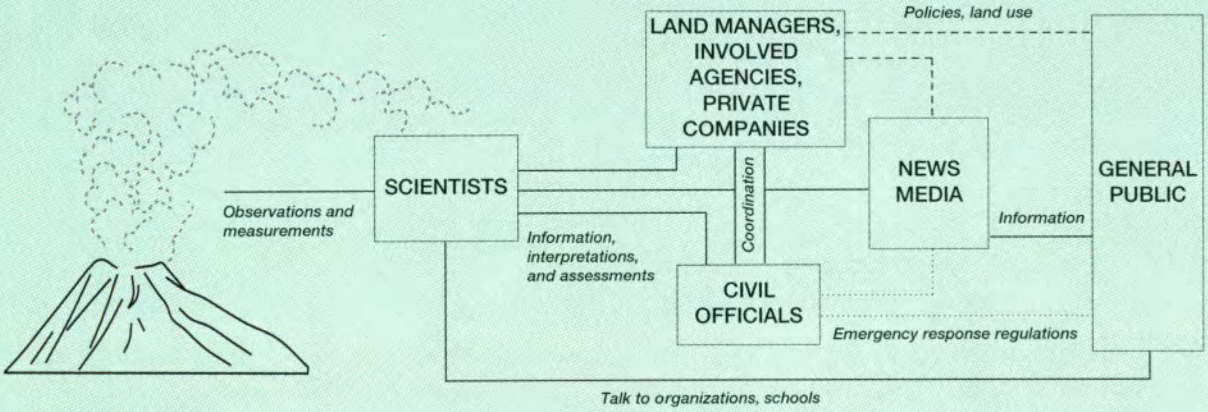
Source: reprinted with permission from Wright and Pierson (1992).

Nevertheless, the optimism of a decade or two ago that science would soon be able to predict earthquakes accurately and efficiently has not been realized. In densely populated Japan, despite a national programme to predict seismic events now in its sixth five-year phase, no earthquake has yet been forecast in terms of place, magnitude and time. The Kobe earthquake of 17 January 1995, in which more than 5 000 people died and more than 26 000 were injured, with an estimated US$100 billion required to rebuild, is a salutary example of how much has yet to be done.

Predicting volcanic eruptions has met with rather more success. Much of the advance has come from research in the USA, which has more active or potentially active volcanoes than any other country except Japan and Indonesia. Potential disasters have been avoided in the Philippines and Indonesia when warnings of major eruptions have enabled local populations to move out of harm's way. However, this is immensely difficult where large populations are involved, as along densely populated coastlines affected by earthquakes and the ensuing tidal waves (*tsunamis*).

To reduce potential damage from volcanic activity it is necessary first to take the pulse of a volcano (Wright

FIGURE 5
COMMUNICATING VOLCANIC RISKS AND HAZARDS



Schematic illustration of the flow of information about Mount St Helens, Washington.

Source: reprinted with permission from Wright and Pierson (1992).

and Pierson, 1992). This is done by monitoring the earthquakes that commonly provide the earliest warning of volcanic unrest. Ground movements caused by the pressure of magma moving underground are measured by detailed surveys to detect changes in distances between fixed markers, ground tilting and variations in elevation. Local ground displacements on steep volcanoes can be the precursors to slope failure and the massive landslides, avalanches and mud and debris flows that can result. Changes in electrical conductivity, magnetic field strength and the force of gravity around a volcano can also indicate magma movements, even when there are no earthquakes or measurable ground movements. Variations in the chemical composition of volcanic gases or in their rate of emission can indicate changes in magma supply or in the pathways for the upward escape of gases. Monitoring the temperature and levels of groundwater, rates of stream flow and transport of stream sediments, lake levels and snow and ice accumulation or melting may also assist in evaluating volcanic hazards.

Geological knowledge of the history of local volcanic activity can lead to much better understanding of the peculiarities of individual volcanoes. From research and monitoring, maps can be constructed to show the spatial distribution of volcanic hazards and risks. However, none of this knowledge may be of any use if local authorities are not convinced that dangers are immediate enough to warn nearby populations, or if the general public does not understand or take seriously advice to move out of danger areas.

When one of the largest eruptions of this century occurred on Mount Pinatubo in the Philippines in 1991, a potential disaster was turned into a responsibly handled volcanic emergency because of close cooperation between local and foreign volcanologists, civil defence agencies and local authorities. In contrast is the tragic example of the loss of over 23 000 people in the Colombian town of Armero, buried by volcano-generated mudflows in 1985, despite the circulation before the eruption of a map showing hazards to be expected (Figure 4). The shock to the nation of

Colombia led to many responses, including the production of an excellent and widely used series of pamphlets, videotapes and other educational aids[1] to explain the nature of natural disasters and how to avoid being harmed by them.

The most significant lesson of recent years is the importance of integrating scientific information with public disaster planning, of building effective communication linkages between scientists and other experts, local officials, planners, developers and public safety authorities (e.g. UNDRO, 1985, Figure 5). Among other requirements it is necessary to understand the difference between volcanic and other disaster forecasts – comparatively imprecise statements – and predictions – relatively precise statements of the time, place, and ideally the nature and size of impending activity. Nature will ensure that seismic and volcanic hazards remain. What humans can do is to understand and reduce as much as possible the potential for damage and, when required, to move out of harm's way. This is one of the main messages of the United Nation's International Decade for Natural Disaster Reduction (1990-2000).

NATURE AND SOCIETY – UNDERSTANDING THE PAST

In our power to disturb nature, the human species now rivals geological processes such as volcanism, earthquakes and erosion. Mass transfer through the extraction of minerals, energy and water resources, through the movement of earth materials for construction and through human-induced erosion, amounts annually to as much as 20 tonnes per person, according to some estimates. This figure is comparable to the sediment volume transported by the world's rivers and to the destruction and creation of the ocean floor by plate tectonic processes. The great tendency today is, thus, to blame all environmental changes on humans. Yet nature itself is not constant, and the causes, frequencies and magnitudes of major environmental changes in the past are little understood.

For example, recent research in the Sahara has shown quite conclusively that where desert now exists there were rivers, savannahs, wildlife and people, not once, but repeatedly (Petit-Maire, 1993). In what is now the hyperarid core of the western Sahara in northern Mali, the fossil and sedimentary record shows that between 8 000 and 4 000 years ago, there were several arid-humid cycles. By 4 500 years ago, sheet floods indicated the onset of aridity, and the lakes began to recede around 4 000 years ago. As the desert set in 1 000 years later, humans moved inland to the inhospitable but wetter mountains of the Aïr and Hoggar, or westwards to the Atlantic coast, where settlement lasted until around the time of Christ. There are many other examples of societies strongly affected or even destroyed by natural environmental 'disasters' (Issar, 1990).

Many studies have shown that when the last great ice sheets were receding from the northern hemisphere, the landscape newly uncovered was one of intense and rapid change, as melt-water channels migrated, ice blocks collapsed and ice-borne sediments were deposited in lakes, river channels and over the barren plains which stood in front of the glaciers. There is no evidence that human or other life forms influenced these events significantly.

Despite the uncertainties in our understanding of natural processes, it is clear that they interact on many scales in space and time, and that they both influence and are influenced by human activities. For example, much of the research on global climate change is concerned with the exchange now and in the recent past of carbon dioxide and other greenhouse gases

1. For schools, there are comics and a well-written manual entitled *Cómo Vivir Aquí* (How To Live Here), which deals with earthquakes, volcanic eruptions, floods, landslides, hurricanes, tidal waves, wildfires and even massive crowds.

Geological indicators of rapid environmental change

In order to assess the state of any environment, reliable indicators are needed, just as doctors use blood pressure and body temperature as guides to human health and as economists use gross national product (GNP) to gauge the health of a nation's economy. The International Union of Geological Sciences is now developing a series of geological indicators of rapid environmental change to assist in long-term environmental monitoring and in state-of-the-environment reporting. Geoindicators are measures of magnitudes, frequencies, rates and trends of geological processes and phenomena occurring over periods of 100 years or less, at or near the Earth's surface, that are subject to variations of significance for understanding rapid environmental change. Geoindicators measure both catastrophic events and those that are more gradual but evident within a human lifespan. Some are complex and costly, but many are relatively simple and inexpensive to apply.

Standard seismic indicators are available for the detection and assessment of earthquakes. Other examples of useful geoindicators include:

- visual observations of beach profiles and vegetation characteristics, which permit rapid assessment of the current stability of beaches and coastlines;
- growth patterns in corals, which can provide detailed information on changes in ocean temperature and salinity, as well as on discharge characteristics of major river systems;
- fluid and gas emissions and ground deformation, which can be used to warn of impending volcanic eruptions.

Where instrumental monitoring is not feasible, certain highly responsive natural settings can provide 'automated environmental monitoring stations' whose records can be read for current and/or long-term changes. These include corals, cave deposits, water in the unsaturated zone and sub-surface temperature profiles.

In searching for sustainability, we cannot afford to ignore important environmental indicators and the minimum datasets required to assess changes in erosion, sea levels, river flow, water chemistry and other earth processes that influence ecosystems and human well-being. Even if it is not now possible to predict environmental changes with confidence, data on the recent geological past are of fundamental importance in establishing the baselines and trends that are required for new models and concepts.

Full details on geoindicators can be found in Berger, A.R. and Iams, W.J. (eds) (1996) *Geological Indicators of Rapid Environmental Change*, Rotterdam: Balkema.

between the atmosphere, the oceans, soils and the biosphere. The massive contribution of volcanic emissions to the physical and chemical properties of the atmosphere is clear, particularly after the ejection of immense volumes of material by Mount Pinatubo (AGU, 1992). This included some 25 to 30 million tonnes of sulphur dioxide, which formed a long-lasting haze of sulphuric acid droplets in the stratosphere, cooling, at least briefly, the surface of the planet by about 0.5°C, and aiding chemical reactions that allow anthropogenic CFCs to destroy ozone.

If we knew exactly how global, regional and local environments have changed in the recent past, we should be able to distinguish more clearly between natural processes and human influences (whether desirable or pernicious) and thus to design better environmental policies to cope with current stresses and future changes. There is extensive historical data on weather and land-use changes, but very much less, for example, on biodiversity, vegetation, water chemistry, erosion, slope stability or peat accumulation. A better understanding is emerging from efforts to read more fully the Earth's archives of environmental change that are preserved in ice cores, lake and oceanic sediments, tree rings, soil temperatures and groundwater isotopes. Managers and decision makers 50 or 100 years from now will have a much better understanding of environmental changes and trends if they are able to draw upon a series of 'snapshots' that characterize the natural environment at any one time.

There is growing evidence from studies of the Quaternary paleoenvironment that natural climate fluctuations of 2°C and more have taken place several times in the last 10 000 years, sometimes quite rapidly.[2] The question then arises as to the effect on climate if either a natural cooling trend competes with anthropogenic increase in greenhouse gases, or a natural warming trend is superimposed on human-induced warming. Climate warming in polar and sub-polar regions is likely to cause widespread melting of permafrost. This would probably release methane gases now frozen into tundra and taiga, causing a feedback effect to accelerate warming further, quite apart from the extensive environmental changes on the ground associated with ground 'softening'. Considerable research efforts are now under way in circum-polar countries to understand and monitor the natural environment for early signs of change in hydrological regimes, heat flow from the tundra and glacier melting, as well as impacts on the biota.

In Canada, the impact of climate on humans in the past century has been greatest in the western prairies, where prolonged droughts between 1917 and 1938 wrought havoc on agricultural productivity and human affairs. Some global circulation models now indicate a potential warming of this region of 3-4°C, which would cause extensive aridification. Indeed, there is some reason to believe that if present trends in land use and climate continue, another 30% of the arable land could be removed from production even without the added greenhouse effect. Work by the Geological Survey of Canada is proceeding on shallow (some less than 1 metre) lakes with no outlets. During droughts, dense hypersaline water forms at the base of the lakes and protects the underlying sediments from the actions of bottom-dwelling organisms and wind. These drought intervals leave a sedimentary record in the form of thin distinctive layers of sulphate or carbonate minerals separated by homogenous muds formed during non-drought periods. Study of sediment cores from these shallow lakes shows that within the past few millennia there have been several droughts, each lasting perhaps a century. This evidence does not fit current general circulation models used to predict global climates and indicates that recent dry spells such as those of the 1920-30s and 1980s may not have been abnormal.[3]

A FINAL COMMENT

The distinction between natural processes and those induced by humans is often blurred. It is not always possible to separate the environmental effects of our activities from those caused by the natural dynamics of the Earth, which would have taken place even if the human species had not existed. Deserts are not simply human-induced, rapid climate changes are not new, and natural earth processes will continue to affect society. Changing policies of land use and management will not necessarily reverse what are natural processes.

Geoscience has an essential role in identifying environmental problems, understanding causes, predicting future consequences and developing solutions, but it can neither resolve all these issues nor cope alone with the effects of natural hazards. To be

2. For example, cores drilled through the Greenland ice cap in 1992 showed isotope shifts that suggest past episodes in the last 40 000 years of very rapid warming – up to 7°C in a few decades. This warming is much more pronounced than that presently predicted by global circulation models.

3. What may have been abnormal, however, were the extensive dust storms and soil erosion that took place during the 1920s and 1930s. The rapid conversion since 1870 to farmland of natural grasslands, which had developed about 10 to 11 millennia ago, degraded the drought-adapted grassland ecosystem, destroying the root mass that would have prevented wind erosion.

effective in forecasting, mitigating and managing the effects of natural earth processes on humans, much more extensive cooperation with the media, planners, politicians and the general public is required. Understanding our environment and the processes that control it is only part of the answer, and science alone cannot provide all the answers. It is but one part of the puzzle, not a 'technological fix'.

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Dr Berger continues his involvement in international matters as Chairman of the IUGS Working Group on Geological Indicators of Rapid Environmental Change.

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Land degradation

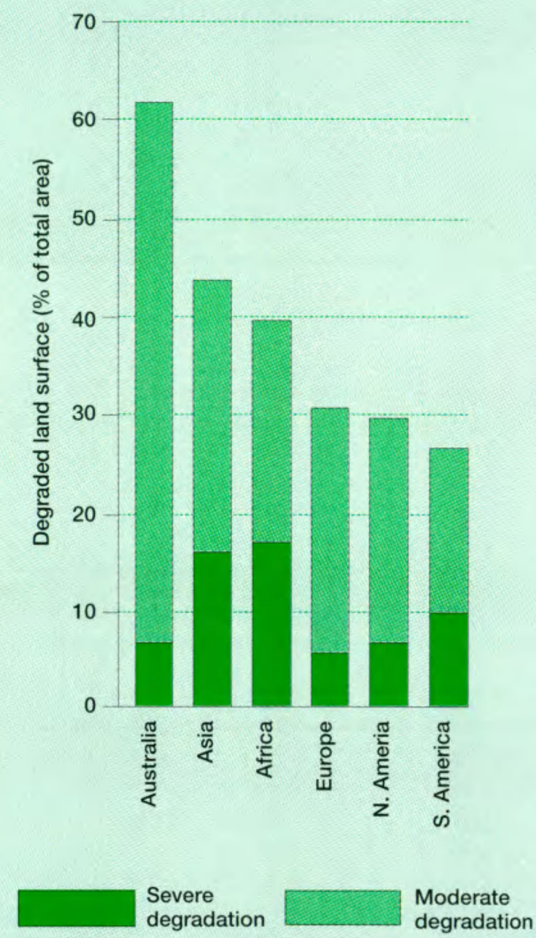
HERMAN TH. VERSTAPPEN

Humankind has, since the dawn of its existence, modified the natural environment in order to survive. The first obvious sign of this is in the disturbance of natural vegetation which, even in remote areas such as the highlands of Papua New Guinea, has a long history: clearings for agricultural production there date back to 10 000 BP. The 'maquis' shrub vegetation, characteristic of large areas of the Mediterranean zone, dates back to deforestation in the days of Greek and Roman civilizations. Further deforestation has occurred all over Europe and in North America since the Middle Ages and has in recent decades been followed by an even more drastic reduction of rain forest in the tropics. Burning practices in Africa are a major cause of the present extent of savannah landscapes.

Such vegetation changes inevitably provoke changes in soil condition, hydrological characteristics and earth surface processes. Some societies have maintained a subtle balance with their environment for many generations and thus achieved sustainability. There are also clear examples from the past, however, of unsustainable practices that resulted in the decline or even the extinction of civilizations.

Land degradation affects subsistence as well as industrialized societies, as is evident from Figure 1. In some areas such as the Mediterranean zone it has a long history, while in others its occurrence is more recent. It has become a global problem in recent decades because of the exploding world population, the rapid increase of economic per capita demands, mechanized farming and logging techniques, large-scale mining and engineering activities, urbanization and so on. As a consequence, not only have the extent and intensity of land degradation increased dramatically, but the orientation of the problem has also changed: in the past, agriculture was a main causative factor, whereas today industrialization and urbanization are mainly responsible. One may even argue with justification that land degradation is too narrow a term: the degradation of the sea and of the air are equally important components of the problem.

FIGURE 1
LAND DEGRADATION QUANTIFIED



Source: Dregne, 1989.

Environmental quality and geodiversity are the basis of biodiversity and are essential for the well-being of humanity. It is urgent that we solve the global problem of creating a sustainable society based on the diversified but limited resources of our planet, yet it is clear that the task is an extremely difficult one. Awareness raising should lead to the change in our attitudes and values that is essential to achieve this aim: the real problem is not nature but our abusive society.

THE MANY FACES OF LAND DEGRADATION

Soil erosion

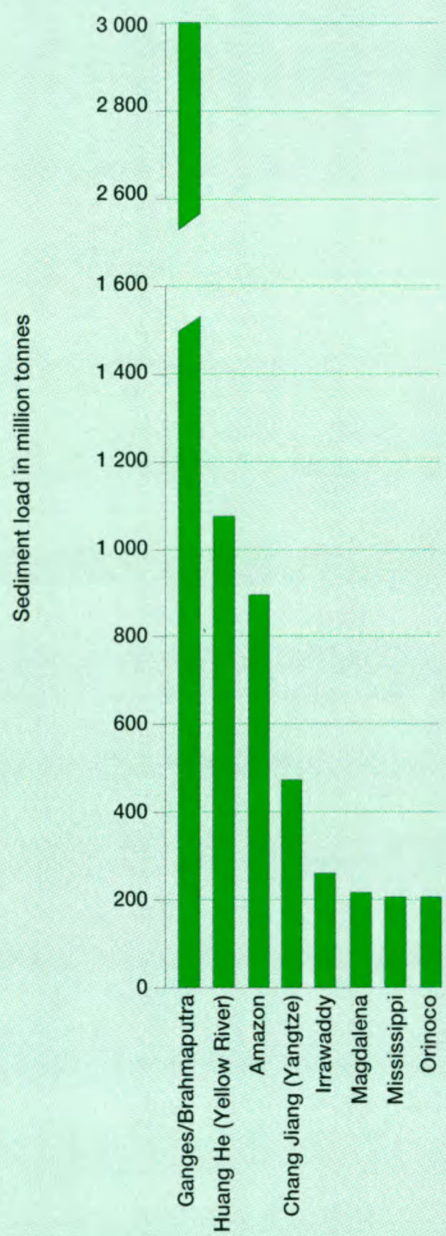
Accelerated soil erosion is the dominant kind of land degradation, notably in hilly rural areas. The processes of erosion involved vary in type and intensity, depending on the local situation. Degradation may start with splash erosion caused by the impact of raindrops on barren soil; subsequently rills and gullies develop (Figure 2), while headward erosion may generate a process of alternating cutting and landsliding. In mountainous areas with thin lithosoils slabs of the entire soil cover may be removed during heavy rains by sliding, leaving only barren rocks.

In all cases, the consequences are decreased infiltration of rain water and increased surface run-off, and thus less soil and air moisture, stronger fluctuations in discharge and a sharp rise in the sediment load of rivers. Flood disasters will thus tend to become more frequent and extensive, and serve to demonstrate the direct relationship between natural disaster and environmental degradation. A small portion of the soil material washed away may contribute to the formation of alluvial plains and deltas further downstream, but by far the greater part is carried off to the sea or deposited in storage lakes and at unfavourable sites downhill or downstream. In most cases the bulk of the material is derived from specific parts of the river basin. The (sharply rising) sediment load of the world's major rivers is given in Figure 3.

FIGURE 2
SEVERE SOIL EROSION IN THE 'BADLANDS' OF CALABRIA, ITALY

There are many widely known ways of preventing, reducing and stopping soil erosion, among which terracing, strip cropping, mulching and reforestation of the upper slopes rank high. Most of these methods are comparatively inexpensive but labour-intensive. Above all, their implementation requires organization and coordination, for which the existence of a local institution which is recognized by the farming community, such as the village elders or a local cooperative, is essential. Action by individual farmers cannot result in a coherent conservation plan. The coordinating institutions can only function properly, however, if land rights are clearly established: the farmers will have no incentive to work hard towards conserving the land if there are obscure government claims on it, or if a landlord can force them to abandon it at will. The importance of these institutions is clearly demonstrated by the near-absence of accelerated erosion in many mountainous parts of Asia, where rural societies of long standing have built and maintained intricate systems of agricultural terraces. Another example is pre-Columbian agriculture in the then densely populated valleys of the Andes: land degradation there began when the numbers of indigenous farmers were severely reduced, their institutions had collapsed and they were replaced by far fewer farmers of Spanish descent, who lacked understanding of that particular environment and of the appropriate institutions. Soil erosion not only causes declining soil and water resources and deteriorating vegetation and climate but will ultimately act as a boomerang on the society that triggered it.

FIGURE 3
SEDIMENT LOSS TO THE SEA BY MAJOR RIVERS



Source: Walling, 1987; Postel, 1989.

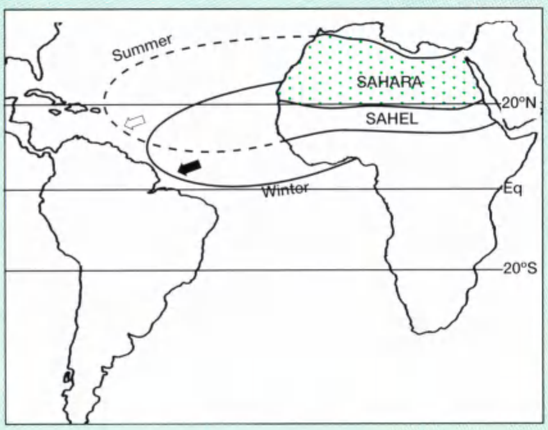
Desertification

Desertification is the second major kind of land degradation that occurs widely in arid, semi-arid and semi-humid parts of the globe. UNEP estimates that it affects 3 100 million hectares of rangelands, 335 million hectares of rainfed croplands and 40 million hectares of irrigated fields, and that annually 20 million hectares deteriorate so as to give zero economic return. The rate of degradation may vary to some extent through the years according to rainfall fluctuations, but it inevitably sets in motion a downward socio-economic spiral in affected societies. Driving factors include increased population pressure with related unsustainable use of agricultural and grassland resources. Crop failure in dry years results in drought and famine disaster, notably in the Sahelian zone of Africa. This kind of instantaneous 'natural' disaster is closely linked with the gradual environmental degradation of drylands. Consecutive years of above average rainfall may increase the hazard: farmers under such conditions are easily lured into moving to even drier parts or into growing more productive but more water-demanding crops on their lands, ignoring the threat of marginality. The strong reduction in percentage grass/scrub cover resulting from overgrazing, notably after dry years, reduces air moisture and may easily introduce a lasting increase in aridity: very little moisture reaches the interior of drylands from outside and up to 95% of the precipitation is generated by repeated local recycling.

Groundwater from wells has to be introduced with great care in herding areas: it can easily lead to concentration of unduly large herds, overgrazing and desertification in the areas around; the natural balance between water and grass resources is disrupted and the animals, in cases of drought, then die from starvation.

Wind is an important destructive element under such conditions, eroding the land by blowing many tonnes of dust into the air and forming dune fields in

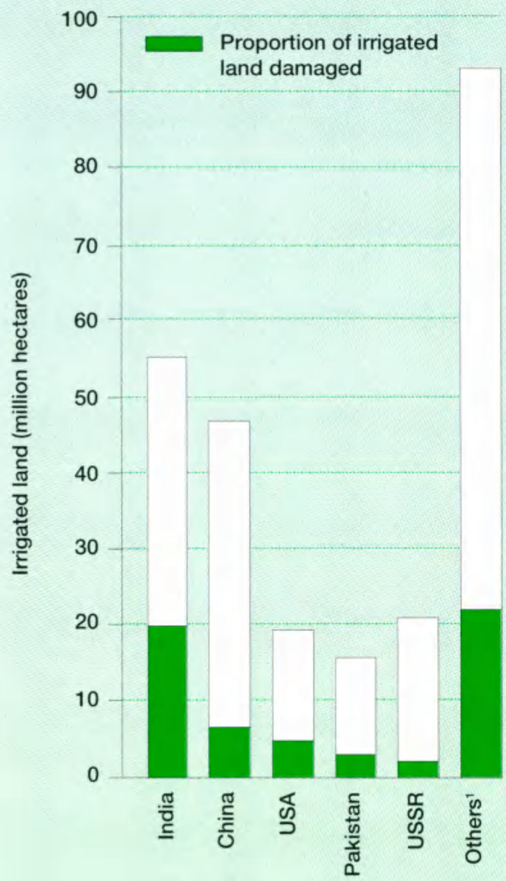
FIGURE 4
DUST TRANSPORT OVER THE ATLANTIC OCEAN AS A RESULT OF THE SAHELIAN DROUGHTS



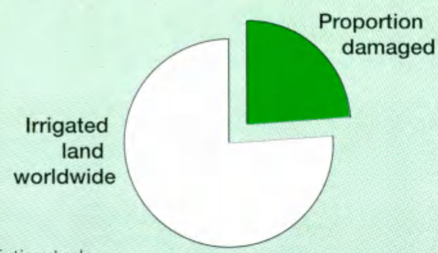
sandy areas. The 'dustbowl' that invaded the dry mid-west of the USA in the 1930s opened many eyes to this phenomenon. Wind erosion has occurred on a much larger scale in Africa, especially during the Sahelian drought of the 1970s and 1980s when great quantities of airborne dust were blown into the Atlantic Ocean (Figure 4). Salination due to evaporation of soil moisture is another common aspect of desertification, threatening the productivity of irrigated fields. An indication of the scale of global damage caused in this way is given in Figure 5, which presents data on the world's top five irrigators in the mid-1980s.

It is increasingly difficult for the rapidly growing populations of drylands to achieve sustainable land use and to avoid desertification. This has led them to develop a range of strategies for coping with drought, from water storage and food gathering to social adaptation. Bushmen, for instance, store water melons and water from zip wells in ostrich eggs, but they also 'disperse in despair' forming groups of 6-10 people that have a better chance of surviving than the usual social groups of 100-200 people.

FIGURE 5
SALINATION DAMAGE TO IRRIGATED LAND, MID-1980s



It is estimated that 24% of a total of 250 million hectares of irrigated land worldwide is damaged



1. Estimated.

Source: Brown *et al.*, 1990.

TABLE 1
ACID RAIN DAMAGE TO EUROPEAN FORESTS, 1986

Country	Forest area ('000 ha)	Area damaged ('000 ha)	Proportion damaged (%)
Netherlands	311	171	55
Fed. Rep. Germany	7 360	3 952	54
Switzerland	1 186	593	50
United Kingdom	2 018	979	49
Czechoslovakia	4 578	1 886	41
Austria	3 754	1 397	37
Bulgaria	3 300	1 112	34
France	14 440	4 043	28
Spain	11 789	3 313	28
Luxembourg	88	23	26
Norway	6 660	1 712	26
Finland	20 059	5 083	25
Hungary	1 637	409	25
Belgium	680	111	16
Poland	8 654	1 264	15
Sweden	23 700	3 434	15
German Dem. Rep.	2 955	350	12
Yugoslavia	9 125	470	5
Italy	8 328	416	5
Other	12 282	?	?
Total	142 904	30 718	22

Source: Brown and Flavin, 1988.

LAND DEGRADATION IN HIGH-TECH SOCIETIES

The multiple threats to our environment that have resulted in recent years from the unsustainable application of modern technology have given the issue of land degradation an entirely new and frightening dimension. Human impact at industrial, urban and engineering sites has been so marked that land degradation has become accelerated, unprecedented and almost irreversible. Dumps of industrial inorganic and urban waste, mining tips, pits and quarries, derelict land in early industrialized and urbanized areas, coastal erosion due to the extraction of building materials from beaches or riverbeds or the construction of storage lakes are but examples. Unfortunately, the damage is not restricted to these sites but spreads through water and air pollution, thus introducing radioactivity, heavy metals, detergents and so on to the wider surroundings. The effect of acid rain on European forests has been dramatic (Table 1).

It would be a mistake to imagine that all land degradation that is due to new technologies occurs in industrialized or urban zones. Bio-industries produce large quantities of organic waste and modern agriculture uses more and more fertilizers and pesticides in rural areas.

Modern technology is also capable of powerful measures to halt such modern kinds of land degradation, but society finds itself sandwiched between its desire to fulfil present needs, real and perceived, and its responsibility for the well-being of future generations.

THE IMPORTANCE OF GLOBAL LAND REHABILITATION

Land degradation is indissolubly connected with social degradation. Whilst we strive to improve the quality of life for the millions, a steady decline in living conditions is already a reality for one out of six human beings. Some highly productive but densely populated agricultural areas like the Nile valley and the Ganges delta regularly require food from outside. Unsustainable land use, leading to deforestation, soil erosion, desertification and other forms of land degradation, goes hand in hand with reversal of economic progress, decreasing food production and deteriorating health conditions. The social context of land degradation is grim and it is therefore essential to match global needs with our planet's resources.

First, we need to develop a global plan for combating land degradation in the context of Agenda 21, adopted by the Earth Summit in 1992, taking into consideration land rights and land tenure issues and fostering community-based initiatives. Further, we should bring our population levels into balance with the carrying capacity of the environment through appropriate family planning programmes and, equally important, bring our per capita demands into balance with sustainability by changing our values and priorities. To achieve these aims we need to bring about coordinated research on society–environment interrelations and we need education at all levels to raise awareness and lead to local action. Land rehabilitation is not an aim in itself but a prerequisite for the sustainable well-being of humankind.

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Professor Verstappen has been President of the International Geographical Union since 1992.

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Biodiversity

FRANCESCO DI CASTRI

During the course of the last decade, and especially since the publication in 1988 of the book of the same title edited by E.O. Wilson, 'biodiversity' has become a very fashionable word. Unfortunately, it is somewhat loosely used, and with different meanings, connotations and intentions. For the general public it usually evokes the preservation of particular animal and plant species of a supposed high aesthetic value or strongly charismatic nature, such as the panda, elephant, sequoias or orchids. For environmental lobbies the paramount objective of their actions is to conserve, as untouched as possible, large portions of ecosystems under threat, particularly in the tropics (tropical rain forests, coral reefs, small islands and so on). For a politician or an entrepreneur, the main concern is the utilization of biodiversity, which involves the property rights of individual countries, and the transfer of know-how towards applications in biotechnology and industry, with special emphasis on pharmaceuticals and the improvement of crop varieties.

The overall geopolitics of an equitable use of biodiversity worldwide is now a very hotly debated matter, linked with the implementation of the Convention on Biological Diversity which was approved in Rio de Janeiro in June 1992 during the United Nations Conference on Environment and Development (UNCED). Admittedly, an underlying dissension still exists between countries of the North and of the South, but this is a real global issue with important conceptual, ethical and economic aspects.

DEFINING THE TERM

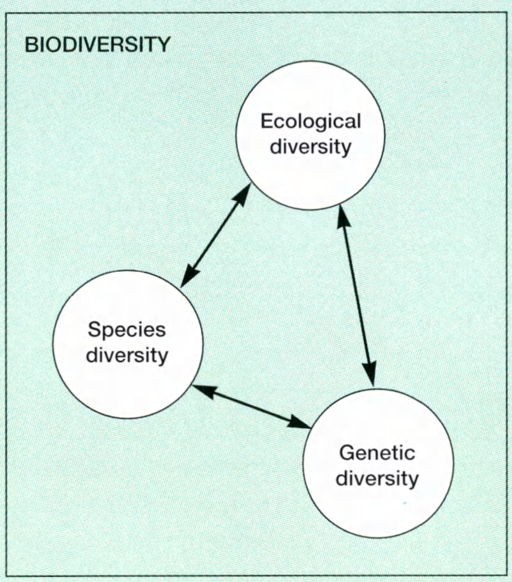
Even the scientific community uses the term 'biodiversity' much too often with too little rigour, sometimes referring only to given taxa (e.g. bird biodiversity or microbial biodiversity) or to a single level of integration (e.g. molecular biodiversity or species biodiversity). The connotation of species diversity is so frequently referred to that it has become – wrongly – almost synonymous with biodiversity. Finally, a multitude of myths about biodiversity pervades the media, and even many textbooks, leading to a sensational or catastrophic viewpoint on the implications of biodiversity and the associated role of humankind.

From this introduction, therefore, it appears that biodiversity is an almost impossible term to define. However, a better understanding of what biodiversity really is has become essential, at least in order to be able to address four fundamental issues. First, it is important that current myths about biodiversity be debunked if the value of maintaining biodiversity is to reach a high level of credibility, a value that is already being contested by some decision makers, as well as by a part of the scientific community. Second, it is essential to eliminate contention among countries during the political negotiations leading to treaties and conventions. Third, the management of biodiversity *in situ* should be based on strong scientific foundations, and not on intuitions or approximations, as is often the case at present. Fourth – and this is probably the most important issue – biodiversity should be able to provide a kind of *leitmotif* that helps to establish a unitary view – about both the uniqueness and the universality – of the biological world. At present, biology is too fragmented into isolated disciplines, but conceptual and operational interactions would easily increase if biodiversity were seen as a range of different levels of organization, from the molecule to the community. Even more, biodiversity is so intimately linked to cultural diversity that what is now considered the almost unbridgeable gap between science and humanities-based culture – from an operational viewpoint – could be crossed more easily both in theory and in practice.

Jutro (1993) records 14 recent definitions of biodiversity from among those more often used. Two of them are of an official nature, since they have been approved by the majority of countries.

The more extended one is that of the United Nations, which was included in the Convention on

FIGURE 1
A DEFINITION OF BIODIVERSITY BASED ON ITS COMPONENTS AND THEIR INTERACTIONS



Biological Diversity of 1992. According to the latter, biodiversity means: 'The variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.'

The shortest definition of all is that of the Global Biodiversity Strategy of 1992, which regards biodiversity as: 'the totality of genes, species and ecosystems in a region'.

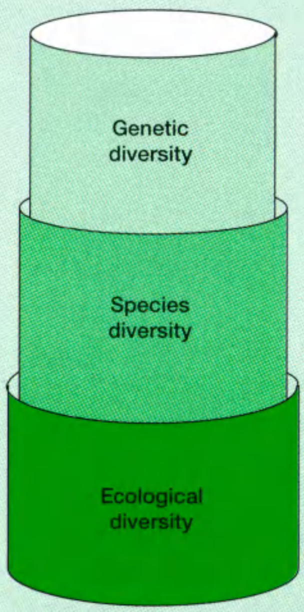
In spite of the fact that the participation of the scientific community in the elaboration of such definitions has been far from satisfactory, both definitions do refer to the three main components of biodiversity: genes, species and ecosystems. Diversity within species is the *genetic* diversity; between species it is the *species* or *taxonomic* diversity; and of ecosystems it is the *ecological* or *habitat* diversity. A scientific shortcoming of both definitions is that they do not mention the interactions within and among the various diversities. And interaction is the main intrinsic mechanism that shapes the characteristics and functioning of biodiversity. Another shortcoming is that the notion of scale seems to have been ignored, while the structural and functional attributes of biodiversity can only be determined by a proper consideration of appropriate scales of space and time.

In the light of the above considerations, the simplest operational definition of biodiversity can be formulated as: 'the ensemble and the interactions of the genetic, the species and the ecological diversity, in a given place and at a given time' (see Figure 1).

It should be stressed that these interactions are of a hierarchical nature, so that emerging properties – that is to say, properties that do not exist at a lower level of integration – appear when passing from the gene to the species up to the ecosystem level. By interlocking the three diversities, as shown in Figure 2, the classical zooming effect of the hierarchical theory becomes clear, whereby new properties of biodiversity emerge according to the relative position of the three blocks of diversities and of the level and intensity of the interactions. Summing up, hierarchy is a central phenomenon of biodiversity, and there is need of a general theory integrating hierarchical levels, how they arise and interact. Additional information on the hierarchical theory can be found in Allen and Starr (1982), Salthe (1985), Nicolis (1986), O'Neill *et al.* (1986), di Castri and Hadley (1988), Vrba (1989) and Vrba and Eldredge (1984).

Admittedly, the hierarchy discussed above is not a 'clean' hierarchy in the strict sense, since genes, species and ecosystems do not belong all together to the same hierarchical category. The concept is expanded and made more accurate in Figure 3, where the hierarchical patterns of biodiversity are shown as the interactions of three different scales of levels of organization: the genetic, the species and the ecological. In this way, the universality of the

FIGURE 2
THE TRILOGY OF BIODIVERSITY PRESENTED AS A HIERARCHICAL ZOOM



biological world is represented, while the unifying principle and the uniqueness are provided by the hierarchical interaction of the various diversities.

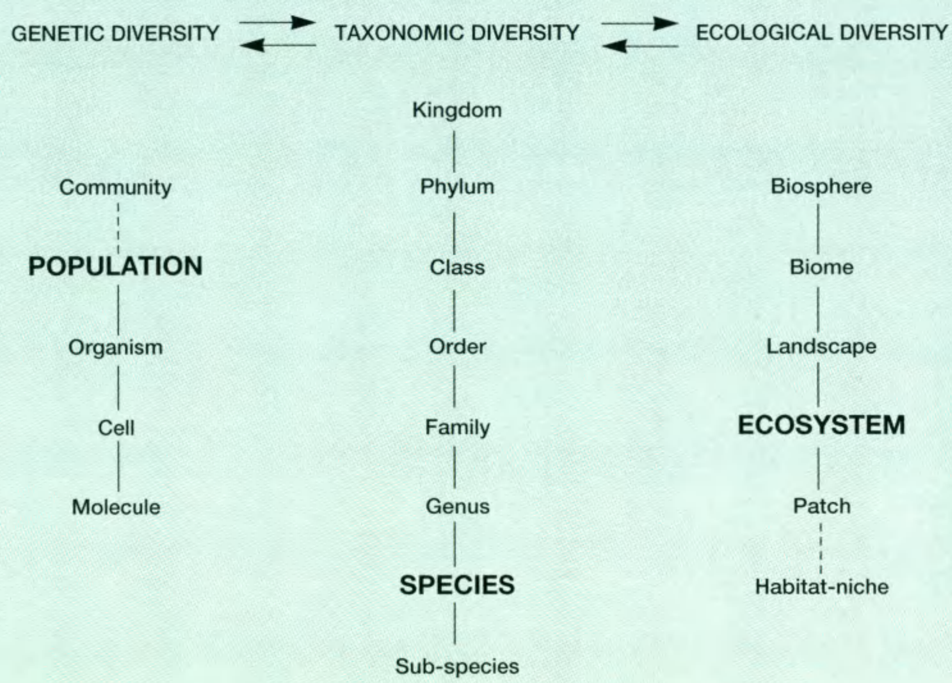
Populations (with their gene pools), species and ecosystems are usually at the cornerstones of the intersection of the three scales (Solbrig, 1991). They are also the three main elements considered in conservation biology and, in practice, they should be viewed together when working for the conservation of rare species or threatened habitats. Even so, this is too restrictive a use of the hierarchical approach.

On the genetic scale, for instance, molecular and population genetics should be very closely linked. On the taxonomic scale, an overemphasis on species diversity could lead to biased conclusions; for example, the marine environment is considered to be poor in species when compared to the terrestrial one; however, there are as many as 28 phyla in the marine environment (13 of them being endemic), as against only 11 phyla in the terrestrial environment, with just one endemic phylum (Grassle *et al.*, 1991). In addition, not all species are equal when it comes to measuring the biodiversity of a system: a few species can play a keystone role in the functioning of the system, while others may be virtually redundant; some species can be represented by a very large number of individuals, thus decreasing the equitability of the system, and others may be present in very low numbers; a very high genetic variability in some populations can, however, compensate – to a certain extent – for a lower number of species. Finally, on the ecological scale, the main factor involved in species extinction may be the fragmentation of landscapes or the disruption of the patch dynamics, and not merely the lack of resilience at the ecosystem level.

The hierarchical organization of biodiversity, when combined with due consideration for appropriate scales of space and of time, cannot, however, be taken as a simple theoretical artefact. From a practical viewpoint, the structural and functional attributes of system stability, productivity and sustainability, as well as patterns of ecosystem functioning (di Castri and Younès, 1990), can only be clarified if hierarchies and scales are considered in terms of their interactions. The same applies, in managerial terms, for the conservation of natural areas as well as for the selection, rotation and mixing of appropriate crops or forestry stands. In addition, the redesigning of more stable and harmonious landscapes, after their disruption due to extended monocultures or massive deforestation, should be based on the interlinking of the three main components of biodiversity.

This concept of the foundations for biodiversity is also applicable when an evolutionary viewpoint is taken. Only these interactions can shed light on whether a given level of biodiversity depends on the evolutionary time that has elapsed without great disturbance, or

FIGURE 3
HIERARCHICAL PATTERNS OF BIODIVERSITY



rather reflects the frequency of repeated disturbances in evolutionary history (Harper and Hawksworth, 1994). It is most likely that both processes are responsible for high levels of biodiversity under different ecological and evolutionary circumstances. The current debate on the emergence of hot spots of megadiversity is closely linked to the above considerations.

EXTINCTION

By adopting large scales of time and space, it could be said that a given biodiversity is the result of differential rates in the processes of speciation and of species extinction. Extinction is intrinsic to the evolutionary trajectory of any given species; it should be approached in scientific terms, free from the emotional catastrophism prevailing today in public opinion and in the media whenever this word is used.

It is roughly estimated that the species presently living in the biosphere constitute only 5-10% of those that emerged by speciation and subsequently disappeared by extinction during the 4 000 million years of evolutionary history. The current rate of extinction is often expressed in thousands of species per year (figures of 10 000 to 50 000 species are usually mentioned, but there are even higher figures put forward by environmental lobbies). All these figures refer to very unreliable approximations, and – incidentally – are mostly represented by species that have not been described as yet; it is very difficult to debate, support or refute figures that concern an unknown biological realm. Nevertheless, it is safe to suppose that extinction is some order of magnitude higher than during previous centuries, that it exceeds enormously the current rate of speciation, and that it is likely to be comparable to those extinctions that

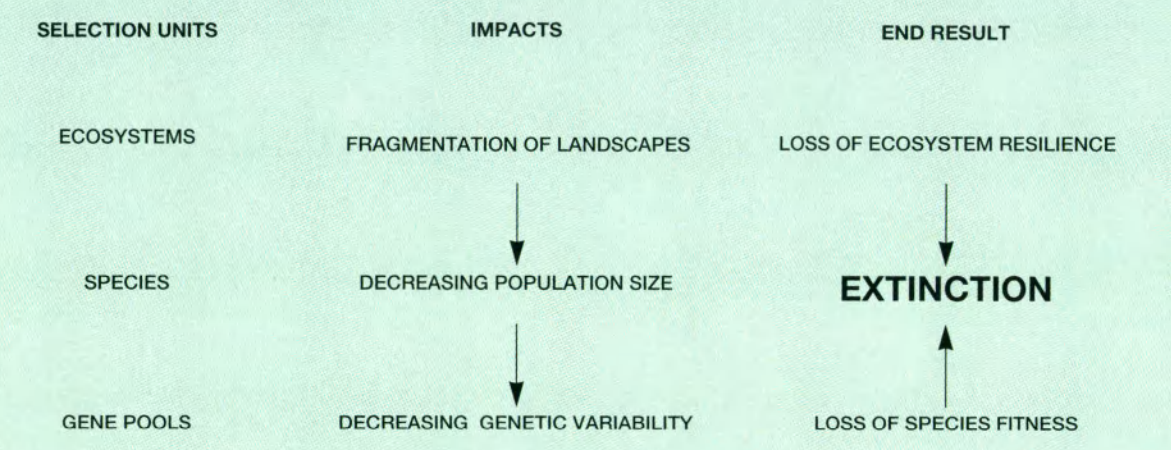


FIGURE 4
IMPACTS AND INTERACTIONS LEADING TO SPECIES EXTINCTION

took place during the so-called periods of evolutionary crisis. The main argument for concern is that the current extinction is occuring over an extremely short period of the evolutionary scale.

Figure 4 illustrates in a sketchy way one of the mechanisms of extinction as provoked by human impacts. It also demonstrates how much the three hierarchical levels discussed earlier – which also represent selection units – are closely linked and interact at a practical level. Contrary to what is usually said in the media and emphasized by environmental lobbies, extinction is very rarely the result of direct and intentional aggression by humans towards a given species (major exceptions being certain large species of terrestrial and aquatic mammals). It is rather the consequence of the common practices of fragmenting landscapes and ecosystems in order to increase the size of areas for intensive agriculture or forestry, of destroying habitats for the purpose of urbanization and transport (railways, roads, etc.), or of drying up wetlands – particularly in the coastal zones – for tourism or industrial activities. Only a proactive and pervasive introduction of environmental concerns in the early stages of development can minimize, through preventive and low-cost measures, the risk of decreasing biodiversity. The more common 'curative' approach is too often prohibitively expensive and – incidentally – impractical or applied as a kind of cosmetic solution.

At the core of Figure 4 is the population size of a given species, as related to the fragmentation of landscapes and habitats. This is of paramount importance from a managerial viewpoint. Above a given threshold of population size, management leading to conservation is possible; below that threshold, management can obtain at best the preservation of a species. There is a fundamental distinction to be made between these two terms which are often confused or considered synonymous. Conservation is a dynamic process; preservation a fixed one. Through conservation, a species still has the genetic and ecological potential to pursue its evolutionary pathways. Preservation on the other hand can only provide conditions for the maintenance of individuals or groups, but not for their evolutionary change; it is frequently defined as 'captive' or 'insular', since it is somewhat similar to the fixist management of a botanical garden or a zoo (Frankel and Soulé, 1981). Unfortunately, management in national parks and other protected areas is much closer to preservation than to the dynamic and adaptive principles of conservation. Humankind has become the main factor of change in the biosphere, even from an evolutionary viewpoint. If man has to assume, therefore, an evolutionary responsibility – as advocated by Sir Otto Frankel – conservation, change and continuing evolution according to the biodiversity laws constitute his main task, his prime mandate.

DEBUNKING THE MYTHS

Biodiversity, as it stands now, is not simply a new approach or a comfortable umbrella to cover all vagueness, but a new emerging science with its own logic: a science that is still facing a dramatic 'unknown' in its theoretical foundations and in its applications. Too many of its aspects remain to be explained, but comprehensiveness would represent an impossible task. I prefer rather to refer to a few other facets of biodiversity by debunking some current myths about it.

Myth: We know how much biodiversity exists

In all probability, we shall never know how much biodiversity exists in the whole biosphere. Genetic diversity is known for certain populations of large species of animals and plants, for some small laboratory animals such as *Drosophila*, copepods and mice, and for a few species of microbes. Ecological diversity can be estimated to a certain extent by direct observation or remote sensing. But we have identified only a minute number of existing species – about 1.5 million – while the conservative estimates of the total today range from 5 to 30 million. Other estimates go up to 50, 80 and even 100 million species. And the attributes of most of the described species are largely unknown. Our main taxonomic gaps concern insects and other invertebrates and microbes; and the inhabitants of some habitats such as the soil, deep lake and sea beds and the canopy of tropical trees. (For a discussion of the measurement and estimation of biodiversity see Hawksworth, 1994.) Unfortunately, there are certain groups of animals and plants for which there are no specialist taxonomists; in addition, in most countries there are no academic or career incentives to become a taxonomist.

In summary, then, there is no place in the world where total species diversity is known, and there is little hope that even in the remote future we shall be able to recognize all species from the terrestrial and aquatic environments. We shall therefore have to accommodate our work to incomplete approximations of biodiversity. And of course these approximations are reliable only to the extent that sampling methods and chosen groups of biota are comparable.

Myth: Biodiversity is all in the tropics

Biodiversity is almost synonymous with life itself. There is biodiversity wherever there is life: that is to say, in the overall biosphere. It is true that high peaks of biodiversity appear in the tropics (rain forests, mangroves, coral reefs and so on). Nevertheless, similar peaks are also present in the Mediterranean-climate ecosystems of the Cape Province in South Africa and of south-western Australia, in the temperate rain forests of Chile, Tasmania and New Zealand, and in certain habitats such as the very humus-rich soils of some temperate deciduous forests.

Myth: We know how biodiversity is changing

We certainly do not know how global biodiversity is changing, since our knowledge of the total number of species and the rates of extinction is too fragmentary and unreliable. It would be possible to remedy this situation to some degree through a globally accepted strategy of selected inventorying in space and of monitoring in time – one of the great hopes of the Rio Conference and of the Convention on Biological Diversity. In the preamble to that Convention, however, there are two consecutive paragraphs that, although quite consistent in themselves, can lead nowhere when interpreted in a too extreme and non-complementary way. These two paragraphs are as follows: 'Affirming that the conservation of biological diversity is a common concern of humankind...' and 'Reaffirming that States have sovereign rights over their own biological resources...'. These are unobjectionable principles *per se,* especially when the use of resources is being referred to. However, in the specific cases of inventorying and monitoring biodiversity, the two views are in confrontation. At one extreme, the process of conservation is conceived as centralized, the essential requisite being global comparativeness. At the other extreme, a 'country-driven' approach is supported: the initiative and the implementation are at the national level, with little concern for what is happening even in neighbouring countries, and with a lack of global framework to provide comparable methodology and design. Understandably, the country-driven approach is dominant at present. Inventorying and monitoring are being carried out in numerous developing countries, with considerable international funding. Different taxonomic groups, with different sampling methods and at different intervals of monitoring time, are being chosen by the various countries, and it is difficult to see what will be the result of such an exercise, even for those nations currently involved. What is certain is that no usable output will emerge for the understanding of the dynamics of global biodiversity. Countries should certainly be deeply involved, but only within a predesigned and previously accepted framework for exchanging results, so that an acceptable level of comparability can be attained. This is a most crucial issue, but I am confident that the current shortcomings will be overcome at a more advanced and mature stage of the implementation of the Convention.

Myth: People have always reduced biodiversity

It is not true that humankind is implacably destructive and intrinsically in opposition to biodiversity. At the early emergence of agriculture, through the selection of many domestic breeds, and the diversification of the landscapes surrounding us, man laid the groundwork for greater genetic and ecological diversity. It is true that this is no longer the situation in most countries of the world: crop genetic variability is decreasing, species diversity faces the threat of extinction and ecological diversity suffers the consequences of deforestation, desertification and the destruction of traditional landscapes. It is my deep feeling, however, that some of these processes will be attenuated for the benefit of development itself.

Myth: We know the function of biodiversity

We know a good deal about the theoretical bases for the functioning of genetic diversity in evolutionary processes, as well as for selecting breeds of domesticated plants and animals. At the ecosystem level, we have some evidence that biodiversity plays a role in shaping given levels of stability, in altering productivity and in influencing patterns of ecosystem functioning, thus reflecting to a certain extent sustainability. Nevertheless, we are almost completely ignorant of the intrinsic mechanisms of these processes. Only research that is more focused on the hierarchical interactions of biodiversity, as discussed earlier in this text, can provide both an explanation of the mechanisms of functioning and a more rigorous perception of the wide projections of biodiversity in space and time.

Myth: Extinctions are unnatural

It has already been stressed that species appear to have a finite life span within an evolutionary perspective. The only aspect that could be considered as 'unnatural' is the current acceleration in extinction, due to a greatly increased human impact.

Myth: We can (and should) save every species

As regards the 'can', it should be said that some decrease of biodiversity – particularly as the result of the conversion of land into areas of intensive agriculture and urbanization, as well as due to marine pollution – is absolutely inevitable. Population growth, poverty and economic pressure are the main underlying factors. The solution advocated by some followers of 'deep ecology' is that of reducing drastically and very rapidly the human population of the planet (not simply the rate of population growth). But such a drastic decrease could only be the result of such events as war, disease and famine. In addition, there is ample evidence that some reduction of biodiversity is compatible with the functioning of ecosystems and the biosphere.

It is more difficult to discuss the 'should', because it implies philosophical and ethical considerations, the main one being that all species have equal rights and that *Homo sapiens* is just another species with no evolutionary advantage over the others. Nevertheless, we must accept that man is the only animal species with the capacity to think about his own destiny and, above all, man has become the main evolutionary factor with an evolutionary responsibility, for better or worse. In practical and managerial terms, it is almost impossible not to have a somewhat anthropocentric attitude to all the other species. Equality of species is, of course, a relative concept, even when species preservation is concerned: I have seen campaigns to save whales or the rhinoceros, but never ones to protect the uncomfortable mosquito. Ultimately, the ambition to save every species implies stopping evolution, and this – if it were ever possible – would be the most 'unnatural' action ever undertaken by humankind.

Myth: Protected areas are enough

The majority of national parks or reserves are not suitable for applying the evolutionary principles of conservation. Most of them are too small and are isolated from their surrounding environments. In the case of global climatic changes, they will act rather as pitfalls for extinction (di Castri, 1991). In addition, they are not representative of all the world's ecosystems. In fact, most biodiversity exists outside the protected areas, including lands devoted to agriculture and grazing. In conclusion, conservation – within and outside protected areas – should be considered as an essential dimension of overall land-use planning.

Myth: A 'hands-off' approach is the best protection

Management by humankind has become the essential condition for both protection and conservation. First of all, evolutionary imprinting by man of most ecosystems means that human action is needed for their regeneration and succession; this is particularly true of ecosystems such as steppes and savannahs, Mediterranean shrublands and forests, and many mountain ecosystems based on the terracing of slopes and the utilization of grasslands. Lack of management may ultimately be the reason for devastating fires, increasing erosion and the loss of open areas for grazing animals and their predators. Secondly, it would be totally unrealistic and unjustified to promote conservation practices without the participation and involvement of the local human populations.

Myth: We know the economic value of biodiversity

The economic value of certain genes, species and ecosystems is well known – and can be expressed in monetary terms – in that they provide the basis for the improvement of domesticated plants and animals, materials for chemical and pharmaceutical industries, the main ingredients of biotechnology and a source of food. But we do not know the enormous capital included in the gene pools of several million unknown species. In addition, it is very hard to evaluate benefits and costs, in monetary terms, of species and ecosystems playing a key role in nutrient cycling, in protecting catchment basins, in preventing soil erosion and so on. And yet, unfortunately, decision makers and industrialists tend to ignore all values that are not expressed in monetary terms. Collaboration between economists and natural scientists could help overcome such a difficulty.

Myth: Biodiversity is antagonistic to development

It is undeniably true that certain developmental activities, mostly those related to urbanization and industry, undermine the levels of biodiversity. However, the paramount importance of biodiversity in many aspects of agricultural and industrial development, as well as in health improvement, has been repeatedly stressed. Humankind has started domesticating species of animals and plants for grazing and agricultural development, domesticating some of their genes for selection with a view to increasing productivity, domesticating microbes for medical or agricultural applications and domesticating ecosystems for constructing more human-compatible landscapes. In the very near future these processes of domestication will increase on an almost inconceivable scale, because of the emergence of new needs and the availability of new techniques. Biotechnology is already an example of the pervasive introduction of elements of biodiversity into almost all productive sectors. And biodiversity, with its three components, will be our main asset at the moment of redesigning and remodeling the territory in which we live in both a pragmatic and harmonious manner, after the irrational and disruptive planning of recent decades. As a response to the current forces of globalization, biodiversity can help shape regional development planning in which economic comparative advantages are taken into account, together with the relevant background of evolutionary and cultural history.

Myth: We cannot act until we know more

In a period of very high economic, geopolitical and social unpredictability, this is the kind of statement that should be rejected categorically, and not only as regards biodiversity. Even scanty information – timely delivered – can be instrumental in helping governmental and private decision makers. Indeed, whilst the Convention on Biological Diversity can be criticized because of its imprecise content, it does represent the best common denominator, arrived at under very difficult conditions of confrontation between the North and the South and considering the lack of knowledge. It is therefore commendable that this Convention exists, in spite of all controversies and uncertainties. Sánchez and Juma (1994) coined the new term 'biodiplomacy' to describe the kind of complicated and unusual negotiations that took place in the build-up to such a Convention.

TOWARDS ACTION

Action must be taken in the field of biodiversity, which in somewhat provocative terms can be defined as our most precious 'unknown'. The precautionary approach should be adopted whenever the level of uncertainty and unpredictability is too high. It can be combined with the 'no regret' approach, in which the action to be undertaken has well defined advantages in addition to those related to biodiversity. For instance, conserving a given piece of habitat also has the result of protecting a catchment area from erosion and of regulating water flow, even when direct action addressed solely to biodiversity may not be regarded as essential; in the same vein, conserving a coastal wetland may be useful in providing a habitat to a migratory bird, but is certainly indispensable for water retention and management as well as the prevention of coastal erosion and the stabilization of the littoral zone.

Reducing uncertainty through problem-oriented research should be an integral part of the developmental process, particularly in such an extreme case as biodiversity. This is also recognized in one of the paragraphs of the preamble to the Convention: 'Aware of the general lack of information and knowledge regarding biological diversity and of the urgent need to develop scientific, technical and institutional capacities to provide the basic understanding upon which to plan and implement appropriate measures…'.

International action on biodiversity

The negotiation and adoption of the Convention on Biological Diversity have given rise to the implementation of a number of large-scale international activities during the course of the past two years.

First, mention must go to *Global Biodiversity Assessment*, a monumental work undertaken by the United Nations Environment Programme (UNEP), financed out of the Global Environmental Facility (GEF) and whose development involved more than 1 100 specialists from some 80 countries.

In another initiative, UNESCO organized an important world conference on biosphere reserves in Seville, Spain, in March 1995, which resulted in the adoption of the 'Seville Strategy', and a statutory framework for the World Network of Biosphere Reserves. These sites, which currently number 325 spread over 83 countries, enable the conservation of biological diversity to be linked with the sustainable development of ecosystem resources to the benefit of local populations, whilst at the same time supporting research, monitoring and training activities.

The Seville Conference gave a new boost to the implementation, within the framework of UNESCO's Man and the Biosphere (MAB) Programme, of this original concept which allows the maintenance, study and use of biological diversity in the most varied of situations.

At the same time UNESCO launched, jointly with ICSU and certain of its principal non-governmental constituent bodies, a major international research initiative on the origin, composition, functioning and conservation of biodiversity entitled DIVERSITAS. This programme, whose secretariat is financed by France and based in UNESCO, is currently made up of the following nine complementary elements: origins, maintenance and loss of biodiversity; ecosystem functioning; inventorying, classification and inter-relationships; assessment and monitoring; conservation, restoration and sustainable use; the human dimensions of biodiversity; soil and sediment biodiversity; marine biodiversity; and microbial biodiversity.

By nature of its breadth, DIVERSITAS should be in a position to provide scientific and technical advice to governments and international institutions for the implementation of Agenda 21 and the various articles of the Convention on Biological Diversity. The World Network of Biosphere Reserves will offer ideal study sites for the programme.

The fact that protected areas can be effective only to the extent that they constitute regional and reliable networks, and that they are part of the overall process of management of a territory – which includes economic, social, cultural and educational components, in addition to environmental concerns – has been discussed earlier in this text.

There would be insurmountable obstacles for any given discipline to tackle in isolation the scientific problems of biodiversity, as well as managerial implications for the conservation of species, ecosystems and the genetic material therein, and their impacts on the industrial and agricultural sectors. No single discipline – certainly not simply genetics for genetic diversity, biosystematics for species or taxonomic diversity, or ecology for ecological diversity – can claim to be able to approach comprehensively the various interactive aspects of biodiversity at a local or global level. If the general theory of biodiversity is based, as a central phenomenon of life, on the hierarchical theory of successive levels of organization and of subsequent emerging properties, it concerns the universality of the biological world in both fundamental and applied aspects. To such universality, biodiversity can contribute by playing a unifying role in view of the pervasive, interactive and non-exclusive nature of its approach.

Francesco di Castri, an Italian by birth, pursued his scientific studies in Milan, Montreal, Santiago de Chile and Padua. Much of his national research activity was developed in Chile, France and Italy, whilst his international scientific work was primarily carried out within the framework of UNESCO and the International Council of Scientific Unions (ICSU).

In 1971 Professor di Castri entered UNESCO as Secretary of its Man and the Biosphere Programme and was Director of the Division of Ecological Sciences from its creation in 1974 until 1984. From 1990 to 1992 he was Assistant Director-General of UNESCO in charge of the coordination of its Environmental Programmes and of the UNESCO contribution to the UN Conference on Environment and Development (UNCED) in Rio de Janeiro (June 1992). He is Laureate of the Global 500 Roll of Honour of the United Nations (1992).

Professor di Castri has held numerous international posts, including Chairman of the UNESCO/IUBS/SCOPE research programme on biological diversity, Diversitas. He is currently Director of Research at the CNRS (France), Special Advisor to the Director-General of UNESCO and Member of the General Committee of ICSU.

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Biotechnology and development

RITA R. COLWELL AND ALBERT SASSON

Webster's Dictionary defines biotechnology, somewhat simplistically, as 'applied biological science'. However, the US government employs a more comprehensive definition: both old and new biotechnologies comprise 'any technique that uses living organisms (or parts of organisms) to make or modify products, to improve plants or animals, or to develop microorganisms for specific uses' (Congress, 1984). The 'new' biotechnology has been defined by the US government as 'the industrial use of rDNA, cell fusion, and novel bioprocessing techniques' (Congress, 1991). However, the definition that in the long run may prove the most descriptive, relative to the world economy, is that of Vivian Moses and corporate biotechnology pioneer Ronald Cape: 'making money with biology' (Moses and Cape, 1991).

Biotechnology has already been employed successfully to manufacture new medicines, improve agricultural production and produce drugs from metabolites of marine organisms, and shows great promise in other areas such as the remediation of environmental pollution. And yet the unique characteristics of microorganisms have only begun to be exploited to improve life on the planet, taking into account of course the role of microorganisms in the cycling of nutrients and in global climate processes.

The most rudimentary application of biotechnology – fermentation, i.e., the use of microorganisms such as moulds and bacteria to produce food products – is as old as human civilization itself. Fermentation technology originated in ancient China, where foods were fermented by moulds, and in Egypt, where beer brewing and bread-making were combined enterprises. Bread, cheese, yogurt, vinegar, soy sauce, bean curd, beer and wine are just a few examples of the products of fermentation.

By the end of the 18th century, farmers had learned to rotate crops to replenish nutrient-poor soil with crops that restored nutrients. Even before the science of genetics was understood, new varieties of crops and animals were being bred by selection for desired qualities. With the advent of genetic engineering, new technologies emerge from the old (Kay, 1993).

GENETIC ENGINEERING: A NEW WORLD

Twenty years after Watson and Crick's discovery in 1953 of the structure of the DNA molecule, the first stones were being laid on the path to commercial genetic engineering. Stanley Cohen of Stanford University and Herbert Boyer of the University of California (San Francisco) Medical School and their teams succeeded in cloning a gene into a bacterial plasmid, the first recombinant DNA. In 1980 they obtained a patent for this technique, which produces recombinant or rDNA. Also in 1980 in the legal case Diamond v. Chakrabarty, the US Supreme Court ruled that microorganisms could be patented, opening a new commercial avenue for genetic engineering.

The first US biotechnology company, Genentech, was founded in 1976. Now, almost 20 years later, it has been joined by more than 1 300 other companies in the USA alone. In 1981, the first US-approved biotechnology product reached consumers: a monoclonal antibody-based diagnostic test kit. The following year, the first recombinant DNA pharmaceutical, Genentech's (Eli Lilly) Humulin®, recombinant human insulin, was approved for sale in the USA and the UK. Humulin's 1993 sales were US$560 million. That same year, the first recombinant animal vaccine for colibacillosis was approved in Europe. For many, 1981-87 were watershed years for US biotechnology: an average of 90 companies were formed annually; a total of 631 companies were established during this period. Although most biotechnology companies are still not consistently profitable, an increasing number of products have entered the market (Congress, 1991). In 1993 Amgen's Neupogen® human granulocyte colony-stimulating factor became the best-selling US biotechnology drug, netting US$719 million.

In 1994, US biotechnology companies had a market value of US$41 billion, total research and development (R&D) expenditure of US$7 billion and 103 000 employees – this, in an industry that did not exist 20 years ago. By comparison, the US pharmaceutical industry, which has heavily invested in biotechnology, had a total R&D expenditure of US$13.8 billion in 1994.

Poor economic markets and policy questions within the USA held down the number of companies formed during 1994. In fact the US biotechnology industry, rather than being in a downturn, may instead be maturing, eventually to take on a new role in the global economy. Instead of being aggressively entrepreneurial, the newly emerging companies may well serve as a reservoir for corporate research for large pharmaceutical firms, which in turn will develop and market the output. A basic change is taking place in the structure of the biotechnology industry: smaller companies are merging. Large companies, such as the major pharmaceutical companies, are acquiring smaller biotechnology ventures and, because there is little money available in the investment market for corporate growth, companies are looking to strategic alliances, both in the USA and abroad, to shore up finances and financial opportunities.

This development may prove beneficial for Asian pharmaceutical or biotechnology companies looking for products in return for allowing access to the Asian market. However, many developing countries, lacking homegrown pharmaceutical giants, will have to look elsewhere for role models for their own fledgling biotechnology industries.

The USA is not the sole provider of biotechnology growth. In 1993 Ernst & Young identified 386 biotechnology companies in Europe (Lucas *et al.*, 1994) most of which are located in the UK, Germany, Belgium and the Netherlands. From 1986 to 1992, 530 million ECU (1 ECU≃US$1.24) were pumped by venture capitalists into the European biotechnology industry. KPMG lists the major biotechnology players in Western Europe as: Belgium, Denmark, France (whose 1991 market for biotechnology products was US$115 million, US$29 million of which were imports), Germany, Italy (with a 1995 biotechnology market estimated at US$1.5 billion), the Netherlands (whose 1991 biotechnology product and process sales equalled US$220 million), Sweden and the UK (KPMG, 1993). In 1993 Canada had 310 biotechnology companies, with revenues of US$1.67 billion and 61% of total sales from export (Going and Winter, 1994). Ten percent of Canada's biotechnology exports go to Japan, while an additional 10% go to China, India, South America and the Caribbean.

There is a handful of companies scattered in South and Central America (mainly in Brazil and Mexico) and Asia (excluding Japan). Some 200 biotechnology companies are located in Australia and an additional 40 in New Zealand (KPMG, 1993).

The Japanese biotechnology industry differs from the entrepreneurial industry in the USA, Canada, Europe and Australia. Much of Japan's biotechnology R&D is carried out by universities, research institutes or in cooperation with its large pharmaceutical firms, food corporations, brewing companies and electronics giants (KPMG, 1993). The R&D outlays of Japan's top 10 pharmaceutical companies equal only one-fifth of similar outlays by US companies.

There are several market segments and research areas in biotechnology, the most important being biomedicine, agriculture, marine biotechnology and the environment.

BIOMEDICAL BIOTECHNOLOGIES

In the USA, and to a lesser degree in Canada and Europe, the bulk of the biotechnology industry is focused on the biomedical field; therapeutics and diagnostics make up 68% of the US, 43.7% of the Canadian and approximately 43% of the European industries. Therapeutic sales in the USA increased from 1993 to 1994 to a total of nearly US$20 billion.

Medical biotechnology includes mainly recombinant drugs and enzyme-mediated diagnostic kits, but the rational design of drugs, where a drug is modelled to fit a particular molecule, yielding a limited response that can result in control of the disease process, has become a significant part of medical biotechnology. By learning more of the basic biochemistry of normal and abnormal cellular function, scientists can eventually produce drugs that will prevent abnormal growth of cancer cells, or permit detection of abnormalities in the DNA that signal the beginning of cancerous changes, thereby preventing cancer from occurring. The intent is to circumvent the immune response to one's own tissue that occurs in autoimmune diseases, such as multiple sclerosis and lupus erythematosus. The hope also is to use small molecules to combat degenerative neurological diseases or to induce neurological cell regrowth in such conditions as Alzheimer's disease, amyotrophic lateral sclerosis, head and spine injury and cerebrovascular accident or stroke. Some of the already successful recombinant drugs include recombinant human insulin, growth hormone, interferons, tissue plasminogen activator, erythropoietin and other blood cell-stimulating factors. Thus biotechnology and pharmaceutical companies legitimately have high hopes for the economic and medical potential of the next generation of drugs.

Among the most successful of the antibody-based diagnostics are pregnancy test kits, which now are so simple to use that they can be purchased over the counter in the USA and Europe and used at home. Human immunodeficiency virus (HIV) testing kits are being sold worldwide and are manufactured in many parts of the world. The US market for monoclonal antibodies, the majority of which are used in such test kits, was estimated at US$1.2 billion this year and to be nearly US$4 billion by the turn of the century. As test kits become both more accurate and easier to use, test kit manufacturers foresee wide application, even in rural settings, by technicians with minimal training. Some companies, for example, have sent personnel to China and South America to train technicians in the proper use of their test kits.

Recombinant vaccines are expected to make a major contribution to the health of the world's population. Recombinant hepatitis B vaccine already has worldwide usage. An HIV vaccine would have enormous use, especially in those countries where HIV is widespread. Unfortunately little success has been achieved and not much is on the horizon, at least at present. Research on HIV vaccines that would be beneficial to those people outside the industrialized nations, who suffer from a strain of HIV different from that found in the USA or Western Europe, is not aggressive. In contrast, vaccines against malaria, respiratory syncytial virus (RSV), rotavirus (which causes severe, life-threatening diarrhoea in children), *Streptococcus pneumoniae* (the pneumoccus that causes bacterial pneumonia) and cholera are actively being pursued and when used widely will have immediate impact on global health (Cohen, 1994). New vaccines and vaccine combinations could result in many more children worldwide being vaccinated. Unfortunately a recent study showed that the vaccine market stands at a mere US$3 billion, a relatively insignificant value compared to the US$1.2 billion in world sales of a single new biotechnology drug, recombinant human erythropoietin (Amgen's Epogen®).

Drug delivery systems are an important segment of the biomedical component of the biotechnology industry. New methods of administering vaccines – by injection, intranasally by spray, time-release methods, and others still under development – and even drugs, could revolutionize health care in developing nations and in poor or rural communities in industrialized countries.

Other, much smaller and specialized medical biotechnology markets include treatment regimens, such as gene therapy. Included in the latter is 'cellular therapy', whereby a patient's cells are treated. An example of this is autologous bone marrow transplants, where a patient's bone marrow is removed, cleansed of cancer cells if they are present, grown in tissue culture, then reinjected into the patient – usually a patient with an advanced cancer – after the patient has undergone therapy to destroy remaining bone marrow. In gene therapy, which currently is extremely limited in use and employed for research purposes only, a normal gene is put into abnormal cells using a carrier, such as a virus. Techniques such as these are prohibitively expensive and therefore very limited in use. Gene therapy requires high-technology medical centres and a high level of training for all staff members involved in patient care. Clearly, even in industrialized nations, these treatments are within the purview only of the very wealthy, the well insured or enrollees of sponsored clinical trials.

AGRICULTURE

Agricultural biotechnology represents a growing segment of the industry: 8% in the USA, 20% in Europe and 28% in Canada, for example. The US agricultural biotechnology market showed an increase in sales of 158% from 1993 to 1994.

Crop improvement

Agricultural biotechnology is expected to become the predominant application of biotechnology in developing countries. Development of transgenic plants, biological pest control, tissue culture techniques for agriculture, microbial products for nutrient cycling, pathogen diagnostics for crops and genetic mapping of tropical crops are major concerns in Africa, Asia, Central and South America and the Middle East. In industrialized nations, the term used to denote the economic value of agricultural biotechnology products is 'value added'. Thus agricultural biotechnology in the USA, Canada, Europe, Japan and Australia aims to produce products such as fruit, vegetables and grains that, due to genetic manipulation, will provide benefits that would cost more or bring greater profit to commercial entities than the standard hybrid product.

Increased ease of transport is an important factor in areas where fruits and vegetables must be shipped long distances to market. Transgenic plants include, for example, the Calgene's Flavr Savr® tomato, in which the addition of a 'backwards' gene results in the tomato producing only small amounts of the ripening enzyme, polygalacturonase. Thus the tomato may be shipped long distances with minimal loss of flavour and ripeness. Since some industrialized nations are dependent upon developing countries for fruits, especially during winter and early spring, these technologies could increase marketability of imported crops.

Introduction of foreign DNA may also result in improved protein quality of some foods, an important consideration for developing countries, not only in human foods, but also in animal feeds. Researchers are also working on improving the nutritional qualities of food starches and oils, as well as biological pest control, a technique used in Asia for several millennia. The latter has made great strides since the import of *Bacillus thuringiensis* into the USA from China in the late 1970s. *B. thuringiensis* is not only engineered for inclusion in many plants, including grains, but it is also being manufactured by recombinant techniques for use as a spray. Other means of biological pest control include virus resistance incorporated into the plant genome. China is marketing a virus-resistant tomato, and potatoes resistant to virus are undergoing tests in Mexico. Scientists in Costa Rica are working to introduce virus resistance genes into the crillo melon. Recently, investigators have identified a number of genes within crops themselves that confer disease resistance. It is only a matter of time before such genes are introduced into non-resistant species.

An important field in agricultural biotechnology will be the use of marker or 'reporter' genes within transgenic species. These genes are attached to functional genes introduced into plant cells and their presence will indicate if the functional genes are working. Recently, researchers at the US Department of Agriculture and University of Wisconsin inserted a gene for green fluorescent protein, derived from the jellyfish *Aequorea victoria*, as a reporter gene into orange tree cells. This is a unique melding of agricultural and marine biotechnology, and is an early example of more genetic introductions to come.

Much of the improvement in crops depends upon improved plant tissue culture techniques and techniques for plant micropropagation. In tissue culture individual cells are separated, genetically modified for desirable traits and grown on nutrient media. Hormonal growth enhancers, nutrients (some of which are produced by tissue culture) and other additives determine the viability of the cells maintained in culture. In micropropagation, tiny plantlets, grown from cells started in tissue culture, all genetically the same, can be grown in culture for distribution to farmers.

Agricultural products do not necessarily result in food for the consumer market. Better plastics and biodegradable disposable items may be produced from plant extracts or refuse. Alcohols and other fuels may be end products of such plant refuse as corn husks and stalks. And plants and animals can be genetically engineered to produce drugs and other biologically active molecules. In fact the entire tobacco programme of the US Department of Agriculture (USDA) is now funded only for research on the production of bioactive compounds from transgenic tobacco plants.

Plants, like humans, are prone to disease, and it is therefore important that diagnostic tests be developed that are simple to operate and can be used early on for the detection of disease.

Another important field in agricultural biotechnology is the use of biofertilizers. Agricultural production can be increased, not only by direct manipulation of plants, but also by the addition of naturally occurring or genetically manipulated microorganisms (Mulongoy *et al.*, 1992) Some of these organisms can be grown in batch fermentors, while others require nurturing on host plants.

Animal husbandry

One of the first approved biotechnology products offered on the market was an rDNA vaccine against colibacillosis. Thus, animal husbandry was among the first sectors into which a commercial biotechnology product was introduced. Transgenic animals such as pigs and cows can be engineered for traits allowing better survival in marginal habitats, the production of more meat of higher quality or even the production of recombinant pharmaceutical molecules for the human health care market. Techniques for *in vitro* fertilization (IVF) were perfected in cattle, allowing breeders to produce multiple embryos from the cows and steers with the best qualities. Using these technologies, cows that carry the offspring need not be the genetic mothers. Not only can biotechnology yield better-quality food animals, it also can improve the health of these animals with new vaccines and diagnostic methods. Improved animal health may lead to increases in trade in meat, animal products and live animals, trade now often restricted due to fear of spreading disease. For example, USDA, Yale University School of Medicine and Virogenetics Inc., of Troy, New York, the latter a biotechnology company specializing in vaccines, have produced a genetically engineered vaccine against Japanese encephalitis in swine, using *Vaccinia* virus and canarypox virus. It is currently undergoing field tests. Because the USA is concerned about importing this disease from Asia, the market for the vaccine may be significant.

One of the biotechnological products that has caused most public controversy in this area has been that of recombinant bovine somatotrophin (BST), or growth hormone, developed by Monsanto. BST serves to increase milk production in lactating cows – by approximately 10-20% – but its use is opposed in many quarters on safety grounds (see below).

MARINE BIOTECHNOLOGY

The oceans represent the last great frontier for the discovery of new materials, medicines and foods.

Yet marine biotechnology represents only a relatively small segment of the biotechnology industry

– in the USA, approximately 85 companies or about 7% of all biotechnology companies – although having applications in medicine, agriculture, materials science, natural products chemistry and bioremediation. Due to the proximity of most of the world's tropical nations to the oceans, and their climates, these nations are particularly well suited to pursue marine biotechnology. Worldwide, marine aquaculture produced 14 million tonnes of fish in 1991, with a market value of approximately US$28 billion.

Aquaculture is the branch of marine biotechnology that is most closely related to agriculture and is often included under that classification. Demand for seafood worldwide is expected to increase by 70% in the next 35 years. Thus, world aquaculture will need to increase production seven-fold by the year 2025 in order to meet the demand. Unfortunately this increase in demand comes at a time when the world's fisheries are overexploited and/or 'commercially extinct'. USDA foresees biotechnology aiding the improvement of captive management and reproduction of species, leading to more efficient species that make better use of food supplies, the production of healthier organisms and improvement in food and nutritional qualities of the organisms. Furthermore, aquaculture can produce organisms used as biomedical models in research, as reservoirs for bioactive molecule production and organisms useful in bioremediation. Aquaculture is no longer a means of producing luxury foods, such as lobsters, but a critical solution to the world's fisheries problems.

Algal aquaculture, an ancient art in Asia, not only produces seaweeds, but also food supplements such as the omega-3 fatty acids and beta-carotene derived from microalgal culture. The polysaccharides of algae are a valuable commodity and a much-sought-after natural product.

Marine biotechnology has numerous applications in areas other than those related to food production. Natural marine products have application in fields as far-ranging as molecular biology and bioremediation, adhesives and pharmaceuticals. Enzymes isolated from thermophilic archaea, microorganisms originally thought to be bacteria, some of which live in deep sea hydrothermal vents, are essential to molecular geneticists carrying out DNA sequencing. Agar, an important ingredient in nutrient substrates for the growth of microorganisms in culture, and agarose, used for making gels for biochemical genetics and protein studies, are both derived from algae.

The strength of adhesives produced by marine organisms such as mussels and barnacles has long been recognized, and with the advent of modern biomolecular techniques scientists have been able to study and duplicate some of these materials.

Some of the most potent natural toxins known to science are produced by marine organisms. These toxins may be used in research applications, such as studies of the neuromuscular junction, where much of their toxic activity is concentrated. They also may yield potent antineoplastic drugs.

Monitoring of the marine environment may give us clues about environmental degradation and help in studies of marine ecology, including the problem of shoreline pollution by bacterial pathogens.

SINGLE CELL PROTEIN

Production of single cell protein (SCP) – a mass of microorganisms along with their nutrient contents – both for animal feeds and human food – has at least a 30-year history (Hamdan and Senez, 1992). Initially work was done on hydrocarbons as source material, i.e., nutrients. The increase in the price of petroleum rendered SCP non-cost-effective. Thus research on SCP has not progressed significantly for the past two decades. Bacteria and yeasts have been used to ferment petroleum products, methanol, methane gas, lignocellulose, spent sulphite liquor by-products of paper mills, molasses, whey and other industrial fermentation by-products. Increased efficiency, however, will be necessary before such processes become economically viable.

ENVIRONMENTAL BIOTECHNOLOGY

Bioremediation, the cleansing of polluted environments, represents a large market force in biotechnology, the potential of which has only recently been recognized. In the USA product sales have increased in the chemical, environmental and services category by 81% during the last year to a total of US$69.9 billion. US federal laws requiring the clean-up of toxic waste sites, surface-mining areas, watersheds and other polluted sites have caused the growth of a bioremediation market which should reach US$500 million per annum by the year 2000, according to a recent US National Research Council report (NRC, 1993). A less conservative estimate is that US$1.7 trillion will be spent on remediation of hazardous waste sites in the USA within the next 30 years (Gibson and Sayler, 1992). This market does not even include known contamination sites in the former Soviet Union. However, Western nations have offered – but not paid – close to US$1 billion for the cleaning-up of these areas. Clearly a sizable percentage of these sites will undergo some bioremediation. In 1993, 10% of Canada's biotechnology companies were in the environmental field, e.g., waste management, biomass, remediation and recycling, and material reuse. In Europe, unfortunately, there are too few firms in environmental biotechnology for a statistically valid evaluation.

Both naturally occurring organisms and genetically modified organisms (GMOs), especially microorganisms, are used in environmental bioremediation. Current practice is to alter the environment of the naturally occurring microorganisms to make them work more efficiently, a process known as 'bioaugmentation'. In general this involves the addition of nutrients, most commonly nitrogen and phosphorus, as well as the control of the oxygen and water contact (Atlas, 1993). Hydrocarbon contamination, i.e., through oil spills, is currently remediated using this technology. Other contaminants, however, are more recalcitrant. Some of the aromatic compounds, polychlorinated biphenyls (PCBs) and other substances, can be removed using genetically engineered microorganisms (GEMs), modified to degrade the target substance or to function in a particular type of environment. For example, the naturally occurring white rot fungus *Phanerochaete chrysosporium* can degrade PCBs, DDT, cyanide, TNT and other toxic soil pollutants. Cellular components, such as enzymes and biological surfactants, also may be used for environmental clean-up.

The *Exxon Valdez* oil spill clean-up provided a valuable case study in bioremediation. Application of oleophilic fertilizer resulted in enhancement of biodegradation, through enrichment of those microorganisms that degrade oil, although there remain some questions about the efficacy of this technique. Other fertilizers were also used, along with specific nutrient enhancement and the addition of microorganisms. Bioaugmentation was clearly effective. However, the addition of microorganisms has yet to be proved to be of value.

Many biological methods have been proposed for the treatment of contaminated sites. For example, composting, a method familiar to all backyard gardeners and farmers by which bacteria and fungi decompose organic material, can be used to treat polluted soils in the presence of oxygen. Composting has been used successfully to clean oiled shoreline waste and soil contaminated with TNT. Some techniques may be utilized *in situ*, where the contamination occurs, in which case oxygen and nutrients are injected using special equipment. Monitoring equipment may need to be brought to the site to establish efficacy and to provide a means of controlling degradation events.

Heavy metals can be removed from contaminated soils by plants that take up the metals and concentrate them: 'phytoremediation'. The plants can subsequently be burned, both to recycle the metals by producing ores and to produce electricity. Researchers are now studying the production of transgenic plants with improved metal uptake capabilities.

Ex situ remediation is done in a bioreactor or filtration system, sometimes in a processing plant or other facility, but not necessarily on site. One interesting combination of *in situ* and *ex situ* bioremediation is the use of Sea Sweep®, an absorbent that is a treated material made from wood-chips. It absorbs spilled hydrocarbons and is used in cleaning oil spills. After use the material is gathered up and degraded by composting. Soybean and rice hulls, rice bran and sugar beet pulp have been found to bind metals and other industrial waste products and may prove useful in environmental remediation.

Waste treatment may take the form of treating solid or semi-solid waste, liquid waste, sewage and industrial and agricultural wastes. Many methods exist, including the use of bioreactors and biofiltration. Biological treatment of raw sewage is but one successful and widely employed method for the treatment of waste materials, an example of environmental clean-up resulting in improved public health. The next step, which municipalities and cities throughout the world face, is what to do with the sludge that remains, as well as solid wastes (garbage). In some communities, sludge is sold for conversion to fertilizer.

Water treatments not only include treatment of wastewater, but also treatment of polluted natural bodies of water. *In situ* treatments consist of the use of microorganisms and localized bioreactors. *Ex situ* treatment may be in a wastewater treatment plant. Microorganisms are being modified for use in wastewater treatment and new methods are being developed to achieve increased microorganism contact with the biomass. Immobilization of microorganisms is one technique that is used. Anaerobic wastewater treatment employing methanogenic bacteria that produce methane as a by-product may be especially useful where an affordable supply of energy, the methane gas, is needed.

The environmental test kit market is growing, as kits become smaller and easier to use, and portable field testing equipment such as ion chromatographs becomes available. Thus, environmental monitoring can be carried out with the use of sensors on a continuous basis. A town in the Czech Republic, for example, has installed sensors attached to an illuminated score board that gives continual readings of air pollutants.

Another aspect of environmental biotechnology is the improvement of air quality and the prevention of both carbon dioxide build-up and ozone depletion which occur as a result of pollutants discharged to the atmosphere. The environmental biotechnology company Envirogen is studying organisms for bioremediation of air contaminated with halogenated hydrocarbons.

Mining

Ore extraction has caused massive environmental degradation in many parts of the world. Brazil's waterways are polluted with mercury as a result of gold mining. In northern Russia, within the Arctic Circle and near its border with Finland, as much as 2 000 square kilometres of forest was destroyed by sulphurous by-products of nickel mining. Engineering of microorganisms, or use of naturally occurring microorganisms to remove ores, is likely to reduce or eliminate this kind of pollution at mine sites, as well as being used for the bioremediation of environmentally impacted mining regions.

Silviculture and the role of forests

The world's forests are being destroyed at a frighteningly rapid pace, the swiftest in history. Mature tropical forests, which are estimated to have covered 15-16 million square kilometres of the Earth's surface, have been slashed in half, and forested land areas continue to decrease. Canada is one of the leaders in biotechnology-based forestry services, earning US$25 billion in 1992. Although most of this income is from the paper and pulp industry, bioremediation of effluent and the addition of bacteria in the paper-making process to decrease toxic effluent and improve paper quality are important research goals. Canadian researchers are also working on trees produced via tissue culture to aid in forest restoration. Investigators in Europe, Canada and the USA have found that invading forest weeds capable of destroying native forest understorey or preventing the growth of young trees can be controlled by the application of mycoherbicides.

Increased CO_2 has a major effect on the world's forests, since 90% of all the carbon contained in terrestrial vegetation is in the forests. Increased atmospheric carbon results in increased growth of temperate and boreal forests. Thus it has been suggested that, to decrease atmospheric carbon, use of fossil fuels must be reduced and instead biomass-based fuels that release little or no CO_2 should be used, as well as the planting of massive, managed tree plantations. The latter is not feasible, but the former is, and biomass energy production is a particularly attractive method for developing countries. Studies to determine the effects of increased CO_2 are under way and researchers are studying microorganisms associated with forest trees to devise new methods of altering carbon partitioning. The Electric Power Research Institute is analysing the use of halophytic, or salt tolerant, plants to sequester CO_2. These plants have added potential as biofuel and to remediate toxic wastewater.

OTHER AREAS

Energy production from biological waste products, although a relatively minor consideration in industrialized nations at this time, will prove important in the future, for developing nations initially and subsequently for those countries that can no longer afford dependence on petroleum products (Ratledge, 1992).

Production of methane from biogas digestors can be carried out on a local or industrial scale. Fermentation production of ethanol may utilize a variety of hexose sugars, but the major sources are sugar cane, maize, wood, cassava, sorghum, Jerusalem artichoke and grains. Waste whey also may be used. Bioconversion processes yield by-products such as single cell protein and enzymes for biocatalysis.

On the cutting edge of biotechnology research – currently too small to be even a blip in the marketplace – are biosensors, bioelectronics, biomaterials and biocomputing (the use of biomolecules in electronic equipment) and the development of molecular machines or submicroscopic molecules, some of which are biological in origin, to carry out specific mechanical or energetic functions within the body. Biosensors have applications in medicine, especially in diagnosis and therapeutics in process control, where biosensors could be used to determine changes in pH, conductivity, molecular concentration or other measurable phenomena; in bioremediation, where bioluminescent organisms could function as reporters; and as environmental sensors. For military use, biosensors could be linked to biocouplers to transmit a sensed event, via a biochip, to a computer system. These could be used for environmental monitoring, terrain monitoring or monitoring of personnel. They could also be used to detect chemical, toxin and biological warfare (CTBW) agents.

Biomaterials may be especially important for the military, since these materials can be used as protective clothing against CTBW agents or as medical materials, such as artificial bone and other tissue, and may also themselves be used as agents of warfare, causing engine malfunctions in enemy vehicles.

Nanomachines produced from biological molecules are predicted to be used as biosensors, in nanoscale manufacturing processes, or even as a means of drug delivery.

Biocomputing will make use of biological material and reactions in computer chips. Bioinformatics, the development of information systems on biology, is a worldwide effort, in which all nations, no matter what their developmental stage, can participate.

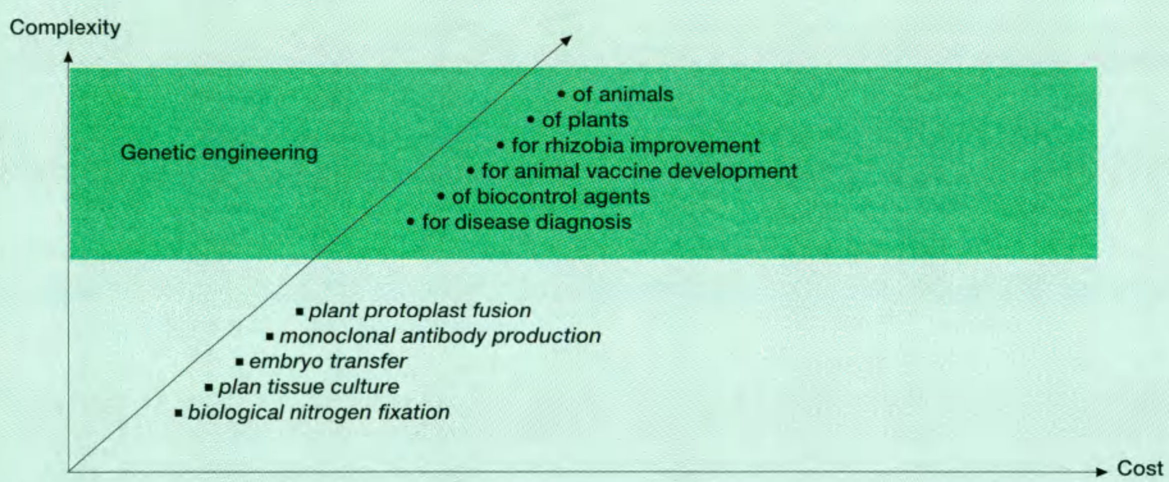
BIOTECHNOLOGY AND THE DEVELOPING COUNTRIES

The various fields of biotechnology can be considered to be on a gradient in terms of complexity and cost (Figure 1) (Sasson, 1993). There can be no real debate over whether developing countries need to move up this gradient: the governments and scientists of even the smallest and poorest nations acknowledge the importance of the field for future well-being and prosperity.

Although most developing countries are not directly involved in modern biotechnology as yet, many are keen to have a national policy and research programme in this field, complemented by strong overseas linkages in both the public and private sectors as quickly as possible. In practice, however, each nation will determine what will best benefit it, within its social, cultural and economic framework. Thus for instance India, a country with a large budget for research, and numerous research scientists and technicians, cannot be expected to adopt the same strategy as a small African country of the Sahel-Sudan zone (Sasson and Costarini, 1991).

Many developing countries are agricultural and depend upon their own agriculture to feed their populace, so the major biotechnological thrust is likely to be in agricultural improvement. Food crops that are better sources of nutrients, have greater yields, are more tolerant of extreme conditions, and resist disease, are likely to have major effects on the food-growing regions of the world, especially the developing nations. Simple methods to improve plant growth, such as the application of biofertilizers to crops, are examples that may require little in the way of technology and would be easy to implement. Biological pest control, especially through use of deterrent sprays produced by GMOs containing genes for the production of natural pesticides derived from plants, bacteria or fungi, uses a technique – spraying – with which farmers are well-acquainted. Disease-resistant animals, animals that can survive harsher

FIGURE 1
THE BIOTECHNOLOGY GRADIENT



Source: Sasson, 1993.

conditions, and animals that are more efficient utilizers of feed, could also have an important effect on world agriculture. Training in tissue culture and micropropagation techniques may help in the establishment or expansion of a locally based industry.

In the developing world there is little by way of commercial biotechnology, but thanks to international and regional cooperation even the least technologically and scientifically advanced countries can reap some benefits from the progress of agricultural biotechnology and participate in the 'biotechnological revolution'.

Government and NGO support have led to the establishment of biotechnology-related centres: for example, the International Centre for Genetic Engineering and Biotechnology (ICGEB), originally developed by the United Nations Industrial Development Organization (UNIDO) but now supported by Italy and India, has two laboratories: one in Trieste, Italy, and the other in New Delhi. Affiliated with the ICGEB are research groups from 32 member countries (*Science*, 1994).

Many national and international organizations maintain laboratories worldwide that carry out research in biotechnology, for the most part related to agriculture, e.g., the International Rice Research Institute in the Philippines. The European Union, in partnership with the Queen's University of Northern Ireland in Belfast, established a Biotechnology Centre for Animal and Plant Health, focused primarily on disease control.

The Agricultural Genetic Engineering Research Institute (AGERI) in Cairo, Egypt, is cooperating with Michigan State University's Agricultural Biotechnology for Sustainable Productivity (ABSP) project, supported by the US Agency for International Development (AID). The African Network of Microbiological Resources Centres (MIRCENs), established by UNESCO, although not a research group *per se*, is organized as a network to support research projects in soil microbiology, biotechnology, natural resources management, vegetal production and protection, and food and nutritional technology, at research organizations and universities throughout Africa south of the Sahara (Da Silva, 1993).

It is generally agreed that the medical biotechnology products most likely to be of immediate benefit to the developing world are vaccines prepared against the major scourges of that world – malaria, hepatitis, dengue fever, HIV and tuberculosis – diagnostics and drugs to treat endemic diseases and highly infectious diseases, and drugs and technologies that will have the widest range of application to increase the health of the populace. Although specialized drugs may not be major commodities in the marketplace of developing nations at this time, some biotechnology firms are nevertheless optimistic. Amgen's Neupogen®, for example, used to treat neutropaenia associated with cancer chemotherapy or bone marrow transplantation, both therapies being prohibitively expensive, is now distributed in China.

Environmental contamination is a worldwide problem, and many developing countries, as well as those of the former Eastern European bloc, have serious environmental problems that are highly amenable to bioremediation. For example it is reported that Asian rivers – even those in more developed areas – are among the worst in the world, containing raw sewage and industrial wastes that compromise public health and threaten entire ecosystems (Lean and Hinrichsen, 1994). However, in many developing nations, environmental clean-up is simply a lower priority than feeding and protecting the health of the population at large.

PROBLEMS IN ADOPTING THE NEW BIOTECHNOLOGIES

Obstacles

Obstacles to the universal adoption of biotechnology projects and products include cultural, educational, economic, governmental and infrastructural problems.

If, for example, there is difficulty delivering agricultural products to market, no change in the quality of these products will overcome the infrastructural problems. There is no reason to introduce genetically engineered apples that ship better in a region where the apples rot on the trees because they cannot be shipped to market. Introducing a complicated test kit for clinical use by marginally trained employees will not yield the expected public health benefits.

When introducing new crops it is necessary to be able to distribute the starter materials and explain to the farmers how best to plant and grow them. Equally, in order to vaccinate people against disease, there must be an infrastructure that will ensure the vaccine reaches the people who need it.

Safety and ethical issues

Monsanto's recombinant bovine somatotrophin (BST), the drug designed to increase milk yield, recently received US Food and Drug Administration (FDA) approval, but a campaign was waged to prevent the drug from being used, and the campaign started long before BST was approved. Concern was expressed that people who drink milk produced by BST-treated cows could be affected by the hormone and that these cows would be more likely to develop infectious mastitis, requiring antibiotic treatment and thereby adding antibiotics to the milk supply. Although it has been concluded by the FDA and others that the product is safe, the economic consequences of treating more than 800 000 of the 9.5 million cows in the USA with the hormone have been that milk production has increased and milk prices have decreased.

Concerns have been raised that genetically engineered crops could become weeds or could transfer the introduced genes to native crops which, in turn, could become weeds. Another concern is that the genetically engineered crop itself may become a pest. Other fears that have been voiced are that plants genetically engineered for virus resistance will cause the emergence of new viral pathogens that could affect other crops, that plants genetically engineered to produce toxins may inadvertently cause illness and/or death in animals feeding upon them and that engineered plants may out-compete wild plant species, altering habitats and affecting other species within those habitats.

Numerous field trials have been carried out worldwide, and since 1987 field tests of more than 860 transgenic crops have been approved in the USA, and at least another 250 tests have been approved in Europe since 1991. Regulation and safety protocols may be put in place with the assistance of international overseeing organizations and by agreements, or through national or local laws. The UNIDO Voluntary Code of Conduct for the Release of Organisms into the Environment was conceived as a basic document from which a more specific code could be built. Governments without the expertise internally can call on advice from the Stockholm Institute for Environment, funded jointly by the Swedish government and the Rockefeller Foundation. Perhaps the establishment of an international NGO commission on GMOs could aid countries that need assistance in formulating regulations and in evaluating projects being considered for implementation within their borders.

Other questions about safety and efficacy revolve around new medical technologies. Clinical trial requirements are more complex in some countries than in others, and review time may be shorter in some countries, allowing a drug to enter the marketplace in Europe, for example, earlier than in the USA. This in itself is not a problem, but will become so if a drug or vaccine is unavailable in the location with the greatest need. For example, in the 1994 bubonic and pneumonic plague epidemics in India, obtaining vaccine was very difficult. An effective vaccine against pneumonic and bubonic plague had been manufactured in the USA by Cutter Laboratories, but in 1992, Cutter sold the rights to the vaccine to another company. FDA regulations required that the vaccine be treated as a new product and undergo testing: thus it was not available when urgently needed. International cooperation, and some foresight on the part of governments, should have been able to resolve this problem long before it became urgent.

Companies may opt for testing a product in a country with fewer controls than the home country. For example, the US National Institutes of Health are delaying tests of an HIV vaccine that many are concerned will not be effective. The manufacturers are considering carrying out trials in Thailand.

Education and public acceptance

A problem that must be addressed globally is public acceptance of biotechnology products and GMOs. Unless the public understands both the value and need for biotechnology advances, opposition to biotechnology products is bound to persist.

For example, some chefs in the USA have banded together to boycott certain genetically manipulated products. The influential Consumers Union opposes the use of some drugs, and the European Union has banned use of BST. Yet most people in the USA are unaware that some cheeses are manufactured using recombinant rennin, and there has been no outcry against use of this product.

Public education should allay some of these fears, and for this reason the introduction of biotechnology products and processes should involve not only the technology but also public education. Farmers, too, need to have factual information to assist them in their decision making concerning GMOs and other products of biotechnology.

Lack of capital

Developing nations need the new technologies which will only be available with investment; but capital is at a premium, although paradoxically the new technologies will provide a source of capital. Thus the new biotechnologies developed must function as a means of creating wealth for the country that develops them (Ratledge, 1992). Products that can be used not only within the country, but also sold on regional or world markets, would be a means to this end. However, protective tariffs may result in attempts to find substitutes for products imported from developing countries, e.g., cane sugar (Barker, 1992). High-fructose corn sweetener, a product of maize fermentation, accounts for 50% of the US sweetener market, a market that previously relied heavily on the import of cane sugar from developing countries. Furthermore, substitutes for other tropical products may become available in a trade atmosphere that discriminates against imports from developing nations. According to the Rural Advancement Foundation International (RAFI), the USA is the world's largest importer of pyrethrum, a natural insecticide from the dried heads of the chrysanthemum, *Chrysanthemum cinerariaefolium*. Kenya is the world's largest pyrethrum producer, with other sources being Tanzania, Ecuador, Rwanda and Tasmania, Australia. If a US company should produce a genetically engineered pyrethrum product, Kenya's $75 million annual trade in the material – much of which is derived from plant micropropagation – might be destroyed.

Developing countries do not have the capital to engage in sophisticated biotechnological research and development. Although they may have the workforce – some of whom may be well-trained – expensive equipment, reagents and process control are beyond their economic means. It has therefore been suggested that it might be preferable if organisms for use in developing nations were researched in the more affluent countries, but that the developing countries should be allowed to reap the benefit of these organisms by growing or maintaining them, i.e., manufacturing, within their own borders. Countries such as China and India, and some funded research laboratories in Africa and other parts of Asia, have the trained personnel, and in some cases may have the necessary equipment. In such instances, the research groups, with any necessary additional support for equipment and supplies being provided, could be expected to carry out the necessary molecular biology research to produce GMOs or related products.

Except for traditional skills, such as those required in planting seeds, use of most of the new technologies will require upgrading the skills of local people and extensive public education to inform the populace about the technologies. The introduction of value-added, high-technology products must therefore include educational programmes.

Technology transfer

The question of technology transfer in biotechnology, not only from the more technologically advanced industrialized countries but also as the transfer of intrinsic knowledge held by local peoples or individuals, needs to be addressed. There is fear, often well founded, within the chemical and biotechnology industries, that their patented materials will not be protected in developing nations (Barker, 1992). Some believe that international agreements, such as the General Agreement on Tariffs and Trade (GATT), will aid in assuaging these fears. Others see GATT as imposing systems that benefit the North at the expense of the people of nations in the South. At the same time, indigenous peoples who share their knowledge of native medicine with researchers and corporations that later develop these materials into drugs, believe they should be rewarded for their information, in some cases with a patent. Unfortunately, a recent review of patent law concluded that this information cannot be protected by patents. It has also been suggested that unique, indigenous plants should be patented, but naturally occurring organisms that are not products of any breeding programme or scientific genetic manipulation are not now patentable (The Crucible Group, 1994). These plants, however, at the very least, might be eligible for protection by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) under newly proposed IUCN – The World Conservation Union categories (Mace and Stuart, 1993-94). Although this would impart no economic rights, it would give originating countries some degree of control over who takes the plants, where the plants are sent and what uses will be made of them.

It has been argued that radical change is needed in the concept of intellectual property, putting value on culturally transmitted knowledge as well as discoveries (Vogel, 1994), although this is unlikely to occur in the near future. Thus we need to work within the current legal constraints.

Tropical nations – rich in genetic resources

The world's tropical nations possess rich biotas. The plants and marine organisms of the tropics are especially valuable sources of medically active metabolites and natural products. Some compounds, although not yet characterized fully, are familiar to indigenous people. How do the more affluent nations, which tend to be in temperate climates, access the riches of the tropics? This is a question that is being debated worldwide and recent agreements, such as the one between Merck and Co. and INBio for the extraction from plant material in Costa Rica, have come under criticism (Joyce, 1994). How are indigenous people who supply knowledge, their lands (resources) and their plant matter to be properly compensated? How are government entities to be compensated, if such compensation is deemed appropriate? Although some of these issues were addressed in the Convention on Biological Diversity, they are not spelled out clearly and none of the current agreements fully addresses them.

In dealing with biological prospecting, also called accessing, all sides have to consider both what is fair and what is workable. Recently a group of international Pew Foundation scholars met to draw up ethical guidelines for bioaccessing. These guidelines cover the behaviour of and interactions with scientists, gene banks and intergovernmental organizations, and propose that scientists treat indigenous peoples with respect, have local people serve as co-researchers and ensure that the local communities receive equitable compensation for any products derived from locally collected and documented plant, microorganism or animal-derived resources. Such guidelines will be effective only if there is a way to enforce agreements. Although the Pew scholars are considering asking professional organizations to enforce member compliance, they also have been considering appending guidelines to an enforceable international treaty, such as the Convention on Biological Diversity.

Guidelines, however, cannot cover all situations – one scholar involved in drafting the Pew guidelines admitted they do not cover his own research situation – but they may aid in reaching fair and equitable agreements. The Brazilian government is considering an Industrial Property Bill that some have suggested should be used as a model to help in determining compensatory agreements between the accessors and the sources of biodiversity.

An added problem in dealing with biodiversity accessing is the enforcement of the Convention on Biological Diversity. The USA, for example, one of the major forces for worldwide conservation, is not as yet an official signatory, although President Clinton, without congressional approval, signed the treaty but with interpretative statements on Article 16 (on technology transfer) and Article 19 (on biosafety protocols). A Republican-dominated Congress is not likely to approve the initiative.

CONCLUSION

Because science is international, international advisory panels, oversight groups, biodiversity consortia, research and granting organizations and scientific societies are agents for problem solving on a global level and for the pooling of resources across national boundaries. International organizations, such as the World Bank and the United Nations, along with international treaties, such as the Convention on Biological Diversity, can sponsor the establishment of databases and networks that allow for greater international communication and cooperation. The technologies are ready for exploitation: it is the financing and the will to put these technologies in place that are needed.

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Albert Sasson received his training in natural sciences at the University of Paris. From 1954 to 1973 his research work at the Faculty of Science of Rabat (Morocco) dealt with freshwater algae, the soil microfauna of arid regions, and free-living and symbiotic nitrogen-fixing microorganisms.

Dr Sasson joined UNESCO in 1974. As a member of the Division of the Ecological Sciences he participated in the activities of the Man and the Biosphere (MAB) programmes. As of 1979 he assumed responsibilities associated with the programme planning of the Organization. He is presently Assistant Director-General for Studies, Programming and Evaluation.

In addition to his research publications on soil microbiology, algology and agrobiology, Dr Sasson has published numerous books and publications on environment, science and development issues, and on biotechnologies.

Information technology

GEORGES FERNÉ

The 'sciences of the artificial', disciplines concerned with the properties and performance of manmade substances or machines, have given rise to most of the new technologies (from mechanics to biotechnology, not to mention new materials and energy) that are now drastically changing contemporary societies and economies. These disciplines, offshoots of the natural sciences whose methods and results they often use, are not rigid ones but have intermittent, often very fruitful, relations with each other.

One radically new area of innovation – information technology – is establishing itself today at the crossroads of mechanics, optics, data processing and data communications, and perhaps, in the coming years, biotechnology.

THE FIELD OF INFORMATION TECHNOLOGY

Information technology (IT) may be defined as the convergence of electronics, data processing and telecommunications. This convergence has two aspects: firstly, the abolition of distance as a result of the worldwide networking of previously isolated computers; secondly, the computerization of telecommunications systems which gives them new capacities for transferring sounds and images.

These meeting points provide new instruments for the collection, storage, processing, organization, transmission and display of information. The development of these increasingly high-performance instruments is profoundly changing the information technology sector by producing a new industrial synergy, as can be seen from the growing diversification of products and the burgeoning of new forms of competition and alliances between computer hardware and data communications manufacturers on the one hand and providers of services on the other. The IT sector is a thriving industry, going full-out after ever bigger markets which in turn bring in more investments, more earnings and more jobs.

But this is not, perhaps, what is most important. By superseding the mechanical and electromechanical processes of yesteryear (or more simply by eliminating routine work that was done by human beings in the recent past), these technologies are making inroads into all other sectors, brightening their prospects of productivity gains and product diversification and enabling them to respond more quickly and more effectively to changes in demand and in the international balance of comparative advantages. By creating new national, regional and world communication networks (for example, the Internet), IT is paving the way to greater ease of movement of technical, professional and financial services, and is thus helping to 'globalize' economies (Pereira, 1994).

It thus encourages the internationalization of production and of markets, increases the mobility and flexibility of services and monetary and financial flows, and often sets the scene for the creation of innovative financial instruments. Information systems are therefore being used to improve the productivity, quality and efficiency of finance, banking, business management and public administration. In manufacturing, and agriculture to a certain extent, many processes have been automated, whether by computer-aided design, the management of resources and stocks, or modes of production using extremely adaptable self-regulating machines or robots.

IT advances may be directly attributed to the recent progress of microelectronics, for scientific and technological results recorded in the fields of transistors, semiconductors and integrated circuits (chips) have been such that they now influence nearly all branches of the economy. The advances of this technology have resulted in a sharp drop in cost prices and much-improved technical performances in the electronics industry as in other branches. The continuous increase in the number of circuits printed on each chip since 1970 has made it possible to cut the costs of assembling electronic equipment very rapidly (because one chip can replace many different components), speed up switching mechanisms (and therefore

The success of the Internet

The Internet grew out of an initiative by the US Defense Department which put an advanced communications network at the disposal of researchers with whom the Pentagon was working. The network was extended to civilian activities by the National Science Foundation (NSF), and soon won over the entire US scientific community. Science researchers overseas who joined the network were equally enthusiastic. The Internet really took off at the end of the last decade, as users from public administrations and businesses all over the world were linked up. User enthusiasm was due mainly to the increasing number of services offered by the network, ranging from easy and direct communication among individuals to access to prestigious documentation services, not to mention its usefulness for promoting business and trade.

The network has two particularly important functions. First, it gives a global dimension to the notion of the research team. Researchers are able to work together, exchange ideas and results, even perhaps carry out joint experiments or simulations without needing to be in the same place: texts, still or moving images and sounds can be exchanged via the 'Net'. This represents a major opportunity for developing countries whose researchers, by avoiding the difficulties that distance creates, are now able to cooperate with their peers from other countries, directly and on a day-to-day basis. On the other hand, there remains the fear that teams working in fields of major strategic or commercial importance will be tempted to form 'electronic clubs', and prevent outsiders from having access to their results.

Secondly, the Internet provides access to the most diversified sources of information. Right now, it gives onto the World Wide Web. The 'Web' connects thousands of servers created by firms, services, universities, common interest groups or even private individuals. These servers offer access to various types of information – text, images, moving pictures and sound – either free of charge or for a modest fee. Thanks to very effective and 'user-friendly' software, travel on the 'Web' poses no real problem.

All this is, no doubt, just a foretaste of the promised 'information superhighways' through which it will be possible to connect homes to computerized sites. It will then be easy to bring about rapid and personalized distribution of documents and gain access to interactive information and programmes of all kinds, including audio-visuals. The major problem to be solved remains the setting up of the network (cable or satellite), which represents an enormous investment and over which many interest groups are already arguing. Here again, developing countries are directly concerned by these new technologies which carry with them so many economic, social and cultural implications.

Decisive choices have to be made and no one can yet foresee how the Internet – which already has more than an estimated 20 million users worldwide – will evolve. The use of the network proper is free of charge; all that is needed is to be linked up to a server (for which there is a charge if one does not have one's own). This has been likened to gaining access to a road network by laying one's own slip road or by paying a toll to use the neighbour's.

In short, the Internet is carrying all before it. But how long can this last? It was not designed to deal with the volume of its present operations, it is not very user-friendly, it does not guarantee confidentiality nor deal equally easily with all types of information transfer, and there are limits to its adaptability.

The key to its success is that it *is* the only easily accessible world network. But there are already competitors for a large number of commercial applications, and others are on their way.

develop faster and more powerful computers), and manufacture more reliable, smaller, lighter hardware (with fewer interconnections, fewer raw materials and lower power consumption). Figure 1 illustrates the dramatic advances with respect to memory capacity.

NEW MODES OF INTEGRATION

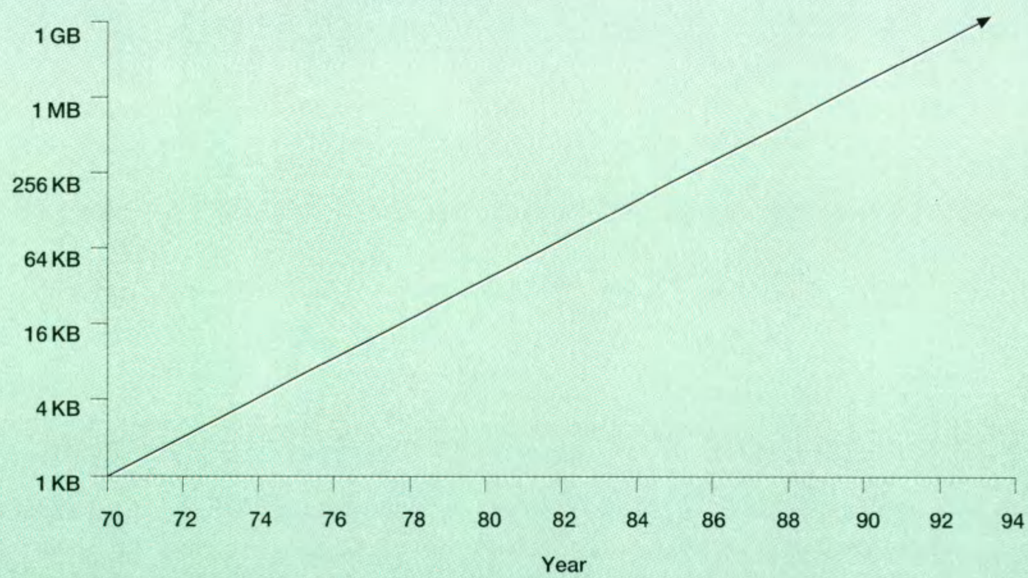
All sectors of the economy are now affected by these developments. IT has led to a redefinition of operational possibilities and economies of scale and scope, and offers the advantage of greater flexibility at all stages of economic activity, ranging from production to the use of labour and equipment, not to mention stock management and the implementation of commercial strategies.

Insofar as they are so flexible as to broaden *ad infinitum* the range of products that can be produced, information technologies offset the disadvantages of mass production, making it possible to respond to the needs of particular segments of the market. An agribusiness firm may, for example, offer 20 variants of the same product in a given country in response to the distinctive requirements of different areas. In the services area special relationships between providers of services and particular customers can result in applications whereby custom-made products can be provided on demand. Customers will no doubt very soon be able to peruse electronically the 'menus' offered by providers of services (banks, insurance firms, etc.) and make up a cocktail to suit their own needs by selecting from among a number of offers.

The swiftness of technological advances in IT will no doubt quicken the already perceptible movement towards greater interdependence in international relations, involving not only economic and financial exchanges but political and cultural aspects as well. National economies are now becoming more sensitive to the consequences of political decisions taken at international level, and national economic measures have a growing impact on other countries' economic policies. World markets for similar products are constantly expanding and opening up, and lifestyles are becoming uniform regardless of national frontiers.

Such prospects are bound to provoke concern on the part of the developing countries. Will they have real opportunities of access to these new technologies

FIGURE 1
GROWTH IN THE MEMORY CAPACITIES OF THE CHIP



KB: Kilobyte, or unit of 1 024 bytes (or octets) of memory stored in binary form.
MB: Megabyte, or 1 048 576 bytes.
GB: Gigabyte, equivalent to approximately 1 billion bytes.

and the information they provide? Will they encounter technical and financial obstacles? What will be the cultural consequences of the globalization of networks, of the ways of dealing with information, and of industrial and trade processes? And what impact will this globalization have on the less vigorous economies that are just beginning to take off?

For there is no doubt that the economic cards are going to be redistributed on a global scale. Progress in telecommunications and computerization enables large firms to use their management and data-processing systems to send technical and economic information to a variety of data processing centres in different geographical locations. Factories scattered over a wide area can now be supervised and managed directly by a central administrative body, to which they are linked by news networks. These developments are affecting the international division of labour, production and trade, modifying forms of industrial ownership and control, weakening the competitive positions of certain countries and giving rise to new trade partnerships. Hence the adoption of new forms of management in 'real time', where the ability to react to unforeseen events can improve competitiveness and also trigger very dangerous chain reactions, as has occurred on several occasions in the globally linked financial markets.

It is the integration of different functions that gives information technology its true economic and social relevance. Rather than being simply a gradual and continuous technological development whose applications make traditional manufacturing processes more efficient (by substituting new technologies for existing systems and rationalizing routine activities), IT makes it possible to devise quite new ways of working by integrating different systems. We are no longer simply applying elements of the new technology to each of the various individual stages of the production process, such as design, production, marketing or distribution. IT can link design to production (for example by integrating design codes into manufacturing, calibration and testing tools); planning and design to marketing and distribution (for example by using computing instruments and databanks that detect and categorize changes in market trends); production to distribution (for example, by introducing the automatic processing by production units of orders placed by customers and with suppliers), and so on. The full integration of all these sub-systems to ensure that all are working together represents a strategic tool for industry in that it offers automated links between hitherto isolated computer hardware previously used for separate operations (Pereira, 1994). But the adoption of these new technological advances calls for profound changes in the organization and behaviour of both business firms and public administration.

TOWARDS NEW TECHNOLOGICAL SYSTEMS

Other technological advances involving telecommunications and inter-computer linkages for the purposes of data transmission will multiply opportunities for systems integration. This type of 'programmable automation' or 'computer-aided manufacturing' (CAM) can integrate data processing into the actual operation of programmable machine tools or robots.

The benefits expected to accrue from these developments are enormous. New forms of management have already made it possible to shorten manufacturing lead times for existing and new products while reducing the volume of stock and improving the organization and performance of services. At the same time, the management and the use made of equipment are becoming more efficient, as is the control of both production and quality. All these improvements can lead to reductions in overhead costs. Medium- and long-term strategy formulation is facilitated by greater precision in decision making, and more reliable forecasts can be made.

Only a handful of the fruits of innovations linked to information technology have been gathered so far, and it will take several decades to harvest them all. Major adaptations, learning processes and structural changes will have to be introduced in today's socio-economic institutions and organizational systems before we can attain a level of integration that will allow all the potential advantages of information technology to be exploited. At world level there remain many technical hurdles (for example, the adoption of common standards for the main interfaces) to be cleared as a preliminary to the establishment of completely reliable and easily accessible world networks. But inflexibility inside the various institutions can be just as great a hindrance. The integrated application of IT by business firms requires a radical reorganization of their working methods, as most organizations still apply a highly specialized and differentiated division of labour with the de-skilling of many tasks, inflexible production procedures and controls, a many-tiered, hierarchical management structure based on bureaucratic decision-making procedures and a mechanistic approach to performance.

In such circumstances recourse to IT often starts with selective and/or local improvements in the technology already being used. Systems based on information technology do, however, offer organizations the prospect of functional integration, versatile manpower, and rapid and flexible decision making with more scope for the delegation of responsibility and for operational autonomy: in other words, a more flexible and organic approach permitting rapid adaptation to environmental change.

As long as world networks and their organizational moorings in national economies and corporations have not moved into the 'information society' and remain trapped in conventional frameworks inherited from another technological age, it will be difficult to take full advantage of technological progress. Where the ground has not been adequately prepared, positive effects such as the establishment of new industries and job-creating services are unlikely to occur, but this will not, unfortunately, be so true of the less positive effects – the delocalization or dislocation of employment markets and also, perhaps, a decline in the competitiveness of certain regions or countries.

GLOBALIZATION AND THE INFORMATION SOCIETY

Throughout the present century efforts have been made to establish new telecommunications structures, but the advantages of information technology, which has been available since the Second World War, have not been so clearly perceived. Fierce competition has pitted both hardware and software manufacturers against each other, and this competition has resulted in a large number of different systems and an accumulation of heterogeneous, often under-used and mutually incompatible hardware. This situation is becoming less and less tolerable: it hampers data flow and network formation and the development of the expected synergies, and thus slows down the spread of IT applications in many sectors.

Since the end of the 1960s, and particularly strenuously during the last decade, each industrialized country has tried to deal with these difficulties in accordance with its own traditions and structures. The development and spread of IT have become an integral part of social, cultural, economic and industrial policy. Each country has sought to identify the most appropriate means of adopting, and adapting to, the new technologies (see the box on international research goals in IT).

HOPES AND FEARS

The field of information technology in general and governments' interest in that field in particular have changed considerably in the last 15 years, as a result of the profound changes that have occurred in social and political attitudes.

At the end of the 1970s, IT raised great hopes and also caused great apprehension. In the quest for greater productivity and economic growth, IT seemed to be the royal road to a new field of technological capacities and innovations that would give rise to the 'post-industrial economy' and the 'information society'. It was generally considered to be the key to a country's future competitiveness. Perceptions of its strategic role led to the launching of special national and international programmes in many countries to support the IT industry, encourage research and development (R&D) and promote education and training: in response to the Japanese fifth generation computer programme the 1980s saw the Alvey programme in the UK, the *filière électronique* programme in France, various programmes sponsored directly or indirectly by the US Defense Department, Dutch, Swedish and Norwegian programmes, and major European Community efforts such as ESPRIT and the EUREKA projects.

The key role assigned to information technology has caused concern, however. It was feared that the spread of IT through the economy would lead to job losses and a rise in unemployment. People were worried about its growing vulnerability to accidental or criminal interference and the serious threats it

International research goals in information technology

At first sight, many national research programmes in the information technology field seem to have very similar objectives. This should come as no surprise. Their main lines are defined by the principal technology trends or 'technology landscape' which each programme is attempting to cover to some extent in order to take advantage of looming technological opportunities which are universally recognized. There are two major strategic orientations. First, to apply the new technologies as effectively as possible in all sectors, while keeping all options open for future (and probably unexpected) developments. Second, to develop and deploy national, regional and global information infrastructures fully capable of coping with expanding 'multimedia' traffic requiring high-speed capability to transfer enormous amounts of information (as text, sound, moving pictures or graphics) for private use, government needs and commerce, through a seamless interconnected web. This web may partly rely on existing connections, but will also demand new cabling to homes and offices.

To be effective, such systems must be based on significant advances in the four main fields of information technology – microelectronics, data processing, telecommunications and computer-integrated manufacturing. Hence the similarities between national programmes and the need for international coordination to establish the common core of the minimum technical infrastructure required. However, beyond this basic technology to be acquired by all, different degrees of autonomy and specialization can be exploited in order to try to conquer specific market niches of varying scope.

MICROELECTRONICS

Microelectronics is a good example of this dual reality. There is one feature common to all programmes: the steadily smaller, and hence steadily denser, chip, which is becoming individually less costly but more expensive to manufacture since the capital investment required is constantly increasing. The targets, such as greater circuit integration, technological improvements in semiconductor design and fabrication, and silicon and gallium arsenide applications, remain unchanged, although the means allocated may differ.

The different countries have a certain amount of leeway concerning the type of product which they wish to develop. Japan has opted for the production and marketing of mass-manufactured standardized components for the consumer goods industry. While attempting to challenge this Japanese leadership, the USA dominates the field of sophisticated components with special applications (weapons, space, etc.). The broad range of objectives assigned to European programmes – from microelectronics to advanced data processing and knowledge (artificial intelligence) – show that Europe has launched a major effort to become competitive in all areas.

posed to privacy. It was even feared that an overconcentration of economic power in the hands of a small number of transnational industrial enterprises would endanger the sovereign rights of states.

Those fears have abated during the last decade, in that form at any rate, owing to the resumption of economic growth. Although the automation of many routine tasks had led to the loss of office jobs, IT was no longer considered likely to bring about mass unemployment worldwide. It began to be seen as a source of skilled employment, particularly in the service sector. This sector has, moreover, developed in a spectacular way as a direct consequence of the spread of IT. What is now emerging is an 'information industry', capitalizing on new telecommunications infrastructures to offer new services to individuals as well as to industry (the French MINITEL is an example of the first generation of the variety of such services that can be provided to all).

Concern over employment is resurfacing in another form, however, in the 1990s. Information technology is no longer considered to be by nature job-destroying. It is the social system that determines the ways in which it is used, and its applications may or may not

DATA PROCESSING

Organizational methods and rules as well as data processing software are changing day by day. An attempt is being made to increase overall computer performance by taking advantage of the improvements in unit components and of new directions in computer architecture, such as parallel processing. Applications offered by artificial intelligence are also being sought in spite of the disappointments of recent years. As a result, potential data processing applications may take an entirely new turn with expert systems, intelligent robots and speech recognition. Each of these applications must be mastered by anyone wishing to be in the running in future, if only to be able to take full advantage of the diffusion of new products as soon as they come on the market.

Aside from these spectacular prospects, less glamorous but perhaps more important work is being undertaken to develop the exploitation systems and communications tools – such as electronic data interchange (EDI) – that will provide a basis from which to launch new global services and establish the instruments required for the conduct of electronic commerce on the new electronic highways.

TELECOMMUNICATIONS

The focus here as been the digitization of transmission systems (which is in fact a measure of the growing convergence between computer and communication technologies) and time switching and the development of opto-electronics as a new transmission process. Everywhere in the industrial world, the major objective has long been the establishment of integrated services digital networks (ISDN) that were expected in future to meet the requirements of all users (firms, services, administrations and consumers) by carrying sound images and texts at high speed and very low cost. Many believe today that these speeds will still not be adequate and that much more effective 'broadband' networks are now required. Hence the major drive initiated by the Clinton–Gore US Administration to deploy global information infrastructures (GIIs), otherwise known as 'electronic highways'.

COMPUTER-INTEGRATED MANUFACTURING

Automation and industrial computing are paving the way towards a two-fold change: a marked increase in production capacity and a broader range of products. They are based on numerical control machines, industrial robots, computer-assisted design and manufacturing systems and visual tactile recognition devices. In short, they are vital for the future of industry and structural adjustment of the economy.

Most of the research in this area aims at improving the diffusion of new applications while developing a specific competitive asset. The technological lead of the USA and Japan is being matched by the European strategy of alliances and groupings with a view to preventing technological dependence. In most European countries (Germany, France and the UK in particular) research is being supplemented by programmes aimed at promoting the diffusion of the new technology.

be structured in order to make staff 'savings'. In the major industrial countries, structures and behaviour patterns have for decades been shaped by long periods of shortages of skilled or semi-skilled personnel during which machines had to be used to do jobs that could not be filled. Now that the problem to be overcome is one of unemployment and dislocation in the world of work, a different form of mastery of technological progress is required, one that would avoid seriously destabilizing social consequences.

If we agree, therefore, that information technology looks set to encourage job creation globally in the medium and long term, then we must also recognize that this technology can also have undesirable effects in this area by leading to the suppression or delocalization of activities: data processing capabilities based on new telecommunications infrastructures have led to 'teleworking', which seems set to develop both nationally and internationally. A European or US firm may thus call on design or administrative staff living in the four corners of the world. Competition obviously thrives in these circumstances, and more attention must be given to making national information technology systems coherent, more efficient and more integrated, so that firms are not tempted to export jobs. But at the same time, as noted above, recourse to new technologies makes in-depth organizational restructuring necessary, which could entail the suppression of whole sectors of traditional commercial and management activity.

THE SEARCH FOR POLICIES

International competition and the need to keep ahead tend towards the rapid and comprehensive spread of these technologies. To avoid the misuse of information technology, the possibility of which has caused public concern, many governments have adopted legislation and regulation that cover both the protection of privacy and the repression of computer-linked crime or data security. In France, for example, the creation of the National Data Protection Commission (*Commission nationale informatique et liberté*, CNIL) has instituted a sort of counter-force that protects citizens from the arbitrary use of computer files. Security measures often involve protection devices that ensure confidentiality for the users of services that transfer funds or confidential information, for example.

Information technology spread quickly once these safeguards were introduced, gathering pace in the last decade in a broad range of sectors, including public administration, banking, air transport and large-scale industry. In the light of recent experience, it has to be said that expectations are not always fully met, however. Certain users have been disappointed that productivity has not yet improved as expected. In fact, the difficulties of adapting organizational structures (arrangements for greater flexibility, decentralization of responsibilities, more creative management methods, etc.) when public administrations and firms adopt new IT systems are sometimes underestimated.

Furthermore, many of the major national and international programmes launched to support the development of IT have been unsuccessful. For lack of an adequate industrial base, it has not always been possible to translate the scientific findings of R&D activity directly into commercial applications. Similarly, national competitions organized to provide the winning firms, as a reward, with a measure of support have sometimes proved disappointing. It has been discovered that the acquisition of advanced technological competence does not necessarily give the countries concerned decisive superiority over their international competitors because factors such as sales methods and progress in the introduction of standards in key markets often count for more.

Governments are therefore making less effort to promote the supply of IT by direct intervention. They now prefer to encourage basic industrial activities in order to acquire or reinforce 'generic' technological capacities in various IT fields such as microelectronics or software engineering, which seem to play a strategic role in maintaining national competence and competitiveness. Above all, there has been a new shift in favour of indirect measures such as deregulation and reinforcement of market mechanisms at national and international levels. But several aspects of the current situation limit the effectiveness of policies focusing on increasing the supply of IT.

One problem is that the market for IT hardware has been very sluggish since the end of the 1980s, as major restructuring by giant corporations like IBM bears witness. This situation is due to current economic factors and general conditions, but it may also be due to deeper structural problems. IT is generally considered to have spread very unevenly through the industrial fabric, through insufficient or misjudged action by certain big firms, and networking that is poor in small and medium-scale enterprises (SMEs) and mediocre in many sectors (transport, urban environment). In certain cases, structural and political problems hinder the introduction of IT (for example the difficulties encountered in establishing systems of integrated management for the various forms of road, rail, air and sea transport). In others (particularly SMEs), it is possible that the modicum of technical skill required to master the new technology is lacking, though it is also possible that more needs to be done to make the technology itself (whether it be a microcomputer or access to a network) more attractive and easier to use – in other words to improve the human-machine interface. Furthermore, the swiftness of technical change in the IT field is making investors fear that they will be unable to recoup the cost of new hardware before being forced to change it.

FUTURE PROSPECTS

A number of recent events in the field of information technology indicate that this sector has entered a period of change and adjustment. Since the end of the last decade, the IT hardware market has grown very slowly, while the software market has continued to expand. At the same time, emphasis has been laid on the development of 'open' standards to facilitate the networking of hitherto totally incompatible hardware (to adapt their interfaces) and to make it possible to run the same applications on different machines (known as 'portability') (OECD, 1991). Legislation or regulations governing the use of IT and to protect users' privacy and security have been put in place in various countries. Users have started demanding, increasingly assertively, to participate in the definition of future IT products (in the hope of obtaining applications more closely geared to their requirements, or standards that are easier to apply).

A number of advances are about to open up new markets to multimedia applications and innovative computer architecture. Future workstations will probably be quite different from those that we know today: they will offer enormous scope for image and sound processing, dialogue and teamwork between distant terminals and the transfer of enormous amounts of information at speeds that are today almost unimaginable.

The move towards total digitization of information processing will also open up a multitude of new prospects for the establishment of international networks. Artificial intelligence, expert systems and even software in general are far from having attained their maximum development. IT is expected to yield applications that will transform work in the liberal professions (legal and medical in particular) and also management methods. The development of 'flexible specialization' in industry is only in its infancy and offers immense scope for the use of software to vary manufacturing methods and the nature of the final product without changing the hardware.

The rapid growth of IT networks thanks to e-mail and tools such as electronic data interchange (EDI) for commercial and administrative exchanges must also be taken into consideration: these new instruments will make it possible to perform administrative and legal tasks electronically. Such tasks could range from customs formalities to tax collection, not to mention

The standardization of IT and its implications

The globalization of the world economy is reflected in the growing interdependence of both industrial firms and countries. Information and communication infrastructures have played and will continue to play a key part in this process, offering the possibility of establishing all kinds of networks. These prospects are increasingly affecting the demand for and priority assigned to standardization in the fields concerned. The growing weight of international considerations may well provide the impetus for changes in national policy and adjustments in the fields concerned. In particular, major users may be expected to press increasingly for the standardization of IT.

The 'bar code' which has had such a resounding success in retail marketing, illustrates the role that users can play. The system was developed on the initiative of major retailing firms in the USA and involved the drafting of standards in cooperation with software producers, then the development of increasingly sophisticated hardware, and lastly the implementation of measures to protect consumers from possible misuse. All these ingredients were necessary for the widespread adoption of the new technology, but the development of standards was particularly important. Coding was not enough: the code had to be readable and usable all along the chain of production, distribution and consumption.

Concern about the efficiency of the standardization system and its effect on the spread of the new technologies has made many participants and observers wonder if a role might be assigned to the users of the technologies concerned. Might it be possible to increase the effectiveness of standardization in information technology, avoid technological stalemates and encourage the spread of new technologies by involving users more closely in the preparation of standards? A nice idea, but is it feasible?

The potential gains of information technology standardization – that is, the harmonization of data-processing systems – are enormous. A system enabling one computer to communicate easily with another is essential for the future of the industrial and commercial infrastructure of the planet as a whole. The aim is to free IT users from total dependence on a single manufacturer and enable them to use a variety of systems comprising hardware and software which although produced by different firms – IBM, DEC or Apple – are nevertheless compatible. Otherwise, the world's data processing, transfer and accessing will remain fragmented and block the development of new industries and new services.

The problem of standardization mobilizes a large number of actors and considerable resources. For example, the total cost of developing standards for open systems interconnections (OSI) has been estimated at US$4 billion over a period of about 15 years. The 1984 start-up budget of one of the organizations concerned (X-Open, a consortium of major corporations) was some US$90 million.

The current process of economic globalization has sharpened the perception of these problems by all users, large and small: small firms too are now interested in world markets. Current standardization mechanisms give rise to all

ordering and invoicing. These networks are extending at great speed, both vertically (involving manufacturers and providers of services, users and administrative services) and horizontally (worldwide). New synergies and unforeseen technological challenges can be expected as a result.

It is hoped that the range of user functions and the attractiveness of IT will be increased through new concepts such as 'fuzzy logic' (which gives the machine 'intelligence' so that it can choose the appropriate programme without the user needing to do anything), or parallel programming for high-speed networks that can process and transmit enormous amounts of information. Such developments would lead to 'integrated intelligence' being built into all products, from household appliances to advanced systems (computer-aided design and manufacturing) and would have direct repercussions in areas as varied as transport, environmental protection, energy savings, public services, health and education, management of urban and rural areas and agriculture.

The IT sector has recently been oriented towards kinds of fragmentation that can be difficult to deal with, as in the case of the standards for electronic data interchange, but globalization logically requires that they should be overcome.

However, information technology producers, who wish to keep their share of the market for their own technologies, will not of their own accord establish a high level of coherence and compatibility that would expose them to even stiffer competition. Only user pressure can achieve this.

In 1991 a first tremor was felt: a group of major IT users (initially composed of American Airlines, Boeing, DuPont de Nemours, General Motors, Kodak, McDonnell Douglas and Merck) drew up a list of requirements, submitted as a sort of general framework for future IT standardization. Many other user groups have formed in the USA, Europe and Japan. More recently, a group of industrial experts on IT standardization was set up by the Organisation for Economic Co-operation and Development (OECD) to prepare a report on mechanisms and procedures for standardization in this field, and on its results, particularly from the viewpoint of users. Although some very large multinational corporations have a higher profile at this stage, the movement is bound to spread from one user to another, and in particular from large firms to their suppliers, which automatically gives it a global dimension.

The conclusions of the Uruguay Round of GATT (the General Agreement on Tariffs and Trade) in December 1993 bear witness to the growing importance ascribed to international standards as an essential element in the installation of the infrastructure of the new global economy, and the agreements in question underline that importance because they affect 115 countries, whereas the previous agreements relating to standardization concluded under GATT were signed by only 40 or so countries. The new agreements:

- encourage countries to participate actively in the standardization work being undertaken by international organizations;
- call on countries to make the available international standards their reference;
- institute new machinery to resolve conflicts and combat the use of standards as barriers to trade.

These developments are all the more significant because the industry is trying more and more to apply international standards, bypassing as far as possible the intermediary stage of national standardization which often leads to greater divergence. Globalization plays an essential role here because it forces multinational corporations, even those that are traditionally highly decentralized and diversified, to strengthen their coordination of certain activities and to form alliances with others. This can only reinforce the demand for international standards.

There is little doubt that new technologies – today information technology and tomorrow materials and biotechnology – call for new approaches in order to tackle directly all those problems that can only be definitively solved through concerted international action. That action must perforce involve the main regions, producers and providers of services as much as users, whose participation would help to set the global aims of today's standardization, moderate its costs and reduce wastage in technical progress.

consumer electronics in which firms are trying to gain a foothold and which will undergo radical change in any case with the introduction of fully digital very high definition television (VHDT). Many people think that VHDT represents a new generic technology that will have enormous implications in many military and civilian fields. This example, in addition to that of the 'information highways', indicates that the IT sector has not yet undergone all the profound changes and mutations that will one day lead to its maturity. But its influence in all areas of society is so great that each one of these technological developments will have a significant impact on the entire socio-economic fabric.

Information technology is not an industry that has reached its peak but, on the contrary, a technology that is becoming more efficient and closely-knit. It will no doubt make a great leap forward with innovations that obviously have many and various applications which cannot be predicted because the impetus will be provided above all by the constant surge of users' expectations and demands. But market arbitration will no doubt be insufficient to ensure the coherence of IT applications within the economic and social fabric, or to limit the scope of possible upheavals at both national and international levels. The range of technological possibilities will be constantly extended while needs will diversify. It will therefore be necessary to develop a new form of relationship between producers and users so that decisions concerning the development of hardware and software will ensure the best possible response to needs. New policies will be required at both these levels to devise new rules for a game whose outcome is still unclear. This will be translated worldwide into a new type of relationship among countries.

Can we ensure that technological progress brings more benefit and minimize possible drawbacks? Can we limit imbalances (and hence conflict at world level) by providing newcomers, and especially developing countries, with effective access to the networks now being formed? Can we help national economies to pull together without destroying the variety that encourages innovation? These political gauntlets thrown down by IT at the end of this millennium indicate the complexity of the tasks that lie ahead.

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The opinions expressed are those of the author only and are not necessarily those of the OECD.

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Materials science and engineering

LAKIS C. KAOUNIDES

In the last 15 years we have witnessed the almost simultaneous arrival of three major generic technologies. These have far-reaching implications for world division of labour, foreign direct investment, the location of production and research and development (R&D) facilities, inter-firm strategic technology alliances, intra- and inter-regional trade patterns and employment. Although information technologies and biotechnologies are much discussed at present, the materials revolution is less well understood and has attracted much less attention. However, as we head for the 21st century, new and advanced materials are set to become crucial determinants of the competitiveness of firms and national branches of industries in the world market, and will provide key solutions to urgent environmental, energy, transportation and medical problems. It is now widely recognized that further technical progress in a wide array of leading industries, including computers and telecommunications, multimedia, aerospace, deep-sea exploration, surface transportation, packaging and construction, to name but a few, depends almost entirely on environmentally sound and high-performance solutions that are offered by materials science and engineering.

Scientists and engineers now have sufficient fundamental understanding of these advanced materials to enable them quantitatively to define and control the relationship between a material's atomic and molecular microstructure, its processing or fabrication path and the resulting properties and performance in use. This means that we are increasingly able to improve conventional materials incrementally and to create new materials tailored to meet the requirements for an escalating performance in end-use applications. Scientists can also begin work from the set of properties required and proceed backwards in order to design and process the appropriate material. At the same time, entirely new materials can be created which may provide the basis for fundamental technological breakthroughs and/or unforeseen applications and industries. These trends are inexorably leading to the need to understand matter at the atomic and molecular level, and to develop the ability to build matter atom by atom and molecule by molecule. This process will be a reality as early as the second decade of the next century, if not before.

Research in both the physical and life sciences is focused on the examination of the elementary constituents of matter. On the one hand, measurable properties of materials are traced back to the microstructures and chemical compositions of the components that give rise to them. On the other hand, the design and intelligent fabrication path of a material determine the properties that the designer wishes to impart to the resulting material or component. This ever-increasing understanding of the relationship between the atomic and molecular synthesis of a material, its processing and fabrication path, the final microstructure and composition, and the observed properties and performance in use, has now opened up an unlimited area of discovery and directed the practical application of functional and structural materials and breakthroughs in medicine and pharmacology, agriculture, mining, genetic engineering, energy and the environment.

In this chapter we first examine the origins and characteristics of the materials revolution and review developments in specific classes of materials. This is followed by a reflection on some of the key implications for countries and regions in today's competitive scientific and technological manufacturing environment. The basic message is that technology and industrial strategies must be strongly and inseparably linked to a materials strategy and vice versa.

THE HISTORICAL ORIGIN OF THE MATERIALS REVOLUTION

The insights offered by quantum physics in the early part of this century greatly enhanced our understanding of the interconnections between the structure and properties of matter. In the decades that followed, the analysis, synthesis and processing of materials benefited from the incorporation of more fundamental scientific understanding, leading to advanced materials entering the production of various fields – atomic energy, electronics and space programmes, amongst others. Nevertheless, such enhanced theoretical insights could only offer qualitative guidelines to modelling and prediction.

It was only very recently that fuller advantage could be taken of quantum insights. Since the beginning of the 1980s a proliferation of powerful new instruments such as the scanning tunnelling electron microscope have been able to provide scientists with in-depth insights into the electronic, atomic and molecular structures of materials. Moreover, the exponential increase in computer power, through the use of high-speed supercomputers, has enabled scientists to develop mathematical models of the very complex physical, chemical and mechanical behaviour of both monolithic and composite materials. Using advanced computer-aided instrumentation, mathematical modelling and experimental techniques, materials scientists are now beginning to offer quantitative characterization of microstructures, thus describing the structure of a material as it evolves during processing, and its relation to the resulting properties. Work is already underway, albeit at an initial stage, in extending the quantitative characterization of the behaviour of materials at the level of the interaction between large groups of atoms and electrons, using the laws of quantum and statistical mechanics, and incorporating the findings into materials design.

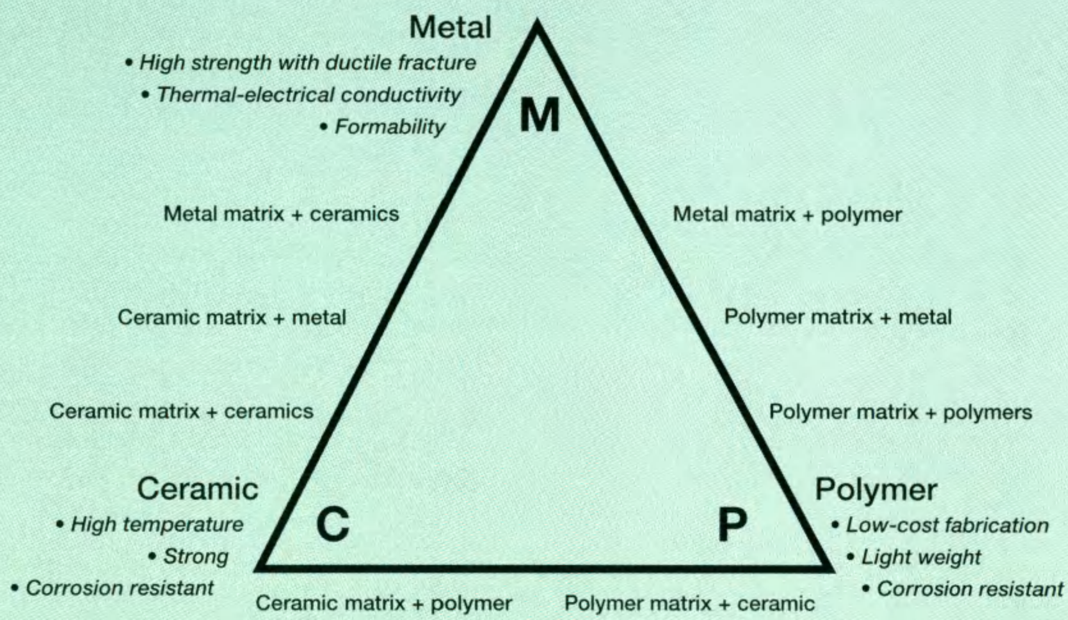
MODERN MATERIALS SCIENCE AND ENGINEERING (MSE)

Modern MSE has emerged from its diverse scientific roots in condensed-matter physics, solid-state chemistry and synthetic chemistry, combined with practical engineering and manufacturing experience and industrial R&D laboratory research, to offer a comprehensive approach to materials. At centre stage is the close interaction and relationship between the structure/composition, properties and performance of a material in use, and the synthesis/processing path that was used to create it. This approach is now both necessary and applicable across all classes of materials, thus rendering all other empirical and craft-related approaches to materials development obsolete. Improvements in existing materials and the introduction of new materials are thus predicated on the methods and tools of a modern MSE, with a strong component of pure science coupled with a comprehensive processing, fabrication and engineering base. Given the permeation of modern MSE across all classes of materials, there is a sense in which all materials are becoming 'new' materials. By the late 1980s, materials science and applied research achieved greatly enhanced capabilities for manipulating and building materials, for example, at the atomic level, which would have been inconceivable at the beginning of the decade.

The 1980s and 1990s: understanding and controlling the structure and properties of matter

It is this, almost incredible and ever-increasing, ability of materials scientists to intervene at the electronic, atomic, molecular and microstructure levels, quantitatively to characterize, model, predict and control the evolution of microstructures along the processing path, and to manipulate and enhance properties in order to achieve desired industrial and military applications, that lies at the core of the materials revolution. It is responsible for great improvements in the properties and processing technologies of existing traditional materials and the proliferation of knowledge-intensive, high-performance materials such as advanced ceramics, engineering polymers, advanced metals and composite systems (Figure 1). Although the 1960s and 1970s witnessed the introduction of important new materials, which could be viewed as advanced materials, I wish to focus

FIGURE 1
ADVANCED MATERIAL SYSTEMS



Source: ALCOA, Position Paper from the 10th Biennial Conference on National Materials Policy.

upon the 1980s as marking a structural break in the mode of development and utilization of materials in industry. The revolution in MSE, and its exponential ability to understand the forms and behaviour of matter, and predict and control its form and uses, is leading to massive transformations in both materials-producing and materials-using firms and industries.

MSE is multi-disciplinary

The need to examine the manifold aspects of materials structure, composition, characterization, synthesis, processing and fabrication techniques involves the integration and interaction of many hitherto specialized fields and disciplines, increasingly pooled in synergistic collaboration. Materials science is now a multi-disciplinary science requiring inputs from solid-state physics, chemistry, metallurgy, ceramics, composites, surface and interface sciences, mathematics, computer science, metrology and engineering. In fact, rigid separation of the different disciplines is becoming inappropriate as barriers or boundaries between them begin to erode. The trend in modern science towards an examination of elementary particles, atoms and molecules cuts across materials, whatever their origin, and crosses over and embraces such other fields as biotechnologies and the genetic engineering of living organisms. Indeed recent experience points to a merging of life sciences (molecular biology) and chemical science and polymeric materials. New developments have facilitated the microelectronics revolution. In turn, developments in microelectronics have repeatedly given added impetus to chemistry via, for example, computer-aided molecular design and the efficient search for new active substances, or microprocessor control of the manufacturing process. And new discoveries in physics and biology greatly expand the fields open to chemistry. At present, computers have joined together with biotechnology to create 'bioinformatics', changing the face of research in pharmaceuticals and biotechnology.

Hence breadth of knowledge and synergistic collaboration are now fundamental and inescapable requirements in the conduct of basic research. In any case, what is clear at this stage is that the nature and complexity of the problems in materials synthesis and processing are such that a team effort across many disciplines, involving several professional staff and previously isolated research teams, is now required. Multi-disciplinary materials design, product development and processing capabilities are therefore becoming crucial at the level of the firm, the industry, the university, and the research laboratory – of the economy for that matter – and are, of necessity, becoming international in character.

THE IMPORTANCE OF SYNTHESIS AND PROCESSING

Science into processing

Materials scientists, across the whole spectrum of disciplines and specializations, are becoming increasingly involved in the processing and fabrication stages of materials development. In addition, materials engineers need to be closely attuned to the scientific and theoretical aspects of materials design and modelling. This has made for a close integration of the subject matter of materials science and engineering in terms of its pure and applied aspects, which should be viewed of necessity as a coherent whole. At the same time this has led to a fruitful feedback and cross-fertilization between scientific understanding and the engineering problem of processing materials in such a way as to control structure and improve performance, reliability and reproducibility at low cost. The infusion of science into processing has led to several new processing technologies, without which new materials would have remained curiosities and existing materials would not have registered the tremendous improvements they have displayed of late.

Improving the properties of existing materials or creating entirely new materials is next to useless without the development of the necessary processing technologies and the equipment and machinery to manufacture the components, shapes and subassemblies entering complex engineering systems and final assembly. In metallic materials, the insights of MSE have been utilized to offer dramatic improvements in the properties, performance and processing costs of a new generation of high-performance metals and metal-matrix composites as compared to commodity metals a decade ago. New processing methods, such as rapid solidification processing, metal injection moulding and many others, are leading to great improvements in the performance of metals. At the same time alloys of various types, high-strength steels, metal matrix composites and laminated systems are offering dramatic improvements in performance, costs and manufacturability, thus both fending off competition from ceramics and polymers and opening up new uses for metals.

Developments in steel in recent years, for example, have been the result of advancing frontier knowledge in MSE. A whole range of advanced steels, with improved strength, corrosion resistance and ease of styling (formability), with precisely controlled chemistry and microstructure, can be customized for applications in cars, high-tech buildings and deep-sea exploration. Breakthroughs in steel design and processing methods are resulting in a range of high-strength, low-alloy steels, bake hardened steels, ultraclean steels and advanced coated steels which enable automotive engineers to improve performance, style, comfort, cost efficiency, manufacturing automation and flexibility and recyclability in car design and production. Nearly half of the new steels now used in cars were not available even six years ago. And today's new generation of advanced multilayer coating systems and technologies enable engineers to custom design protection for the surface and underside of car bodies. Ten years ago only 10% of car bodies contained metallic-coated corrosion-resistant steels. By the mid-1990s it was predicted that between 60% and 100% of new cars in the USA, Europe and Japan would be using them.

The synthesis of entirely new materials and greatly improved traditional materials, such as plastics, synthetic resins, fibres, films, pure glasses, electronic and structural ceramics, polymer and metal matrix composites, advanced aluminium and steel alloys, are making possible such products of ever-greater technological sophistication as the new generations of jet engine and aircraft structures, cars, robots, colour televisions, video recorders, etc. The shift of user industries towards high technology and increasing sophistication is placing ever-higher technical and performance requirements on materials, thus spurring the development of new advanced materials possessing entirely new characteristics and combinations of properties unheard of even a decade ago, and the improvement of conventional materials.

Synthesis

Underlying the discovery of new materials with novel properties and exhibiting new phenomena, the improvements in the control of structure, composition and, hence, properties of known materials, and progress in the development of materials processing and manufacturing technologies, lies synthesis.

Although the synthesis element of MSE necessarily retains a large scientific base, it is nevertheless organically connected to the processing and manufacture of solid materials. For not only does the choice of synthetic reactions influence subsequent processing paths, but modern fabrication technologies also involve the merging of the synthesis and processing stages into a simultaneous process, as in the injection moulding of plastics. Thus, materials synthesis, processing, fabrication and manufacturing are merging in response both to forces internal to MSE and to pressures emanating from the evolution of new production technologies, as well as to the ever-increasing need to apply pure materials research to industrial and military purposes.

At present, a major limiting factor in the spread of advanced materials into a wide range of technologies and industrial applications is the ability to process raw or synthesized substances into reliable, high-volume, low-cost useful forms, such as films, wire, components, devices and structures entering complex engineering systems. Nowhere is this more evident than in advanced structural ceramics, composites and the new high-temperature superconductors. But more than this, it is becoming clear that technological competence in materials processing and fabrication is the critical component in international competitiveness between national industrial structures and industrial branches engaged in traditional and high-technology activities.

DEFINING ADVANCED MATERIALS

The US Bureau of Mines in its *1992 Annual Yearbook* (written in 1994), focuses on four broad-based technologies which comprise the bulk of the US advanced materials industry, namely advanced ceramics, advanced polymer composites, metal matrix composites and carbon-carbon composites. Advanced materials are defined as 'polymers, metals, and ceramics fabricated as intermaterial compounds, alloys, or composites. The resultant components have higher strength-to-density ratios, greater hardness and heat resistance, and one or more superior thermal, electrical or optical properties when compared with traditional materials. Advanced materials, the basis for many of today's emerging technologies, offer savings in total energy consumption, improved performance at reasonable cost, and less dependence on imports of strategic and critical mineral resources.'

ADVANCED METALS

Advanced high-performance metals and alloys are at the forefront of advanced materials research, either alone as monolithic materials or with non-metallics in composite materials. They hold an important position in many leading-edge applications in the aerospace industry, such as in military aircraft, subsonic and supersonic civil transport aircraft, space systems and space-based strategic defence structures. Due to their higher cost, advanced metals and alloys have not as yet made great inroads into non-aerospace markets. However, many Japanese companies are diversifying into new materials, including metals. Some Japanese firms are developing metal matrix composites (MMC) for non-aerospace commercial applications, and in fact they dominate sporting goods and engine component applications. Japan and Europe are now challenging the strong US position in advanced metals, especially in Al-Li alloys, MMCs and intermetallics. Europe's challenge is predicated upon the expertise developed in aerospace, while the Japanese challenge is founded upon its strong steel-making capabilities. The activities of US firms in this area are dominated by defence and aerospace markets. Given the importance of advanced metals and alloys as a critical enabling technology, any country or area that wishes to develop and maintain a strong presence in aerospace (e.g. Republic of Korea, Japan, Europe, Brazil) needs to possess strong capabilities in a range of advanced metals technologies. Conversely, if the USA is to retain its leadership in aerospace, it must preserve its pre-eminence in advanced metals.

ADVANCED CERAMICS

Advanced ceramics are materials which derive from the oxides, nitrites and carbides of silicon, aluminium, titanium and zirconium and which are processed or consolidated at high temperatures. These types of inorganic and non-metallic advanced materials have been developed in the last 10 to 15 years in response to specific industrial and high-tech needs.

Advanced ceramic materials are increasingly applied in fibre optics, electronic substrate and circuitry for computers, new active and passive electronic materials, in connection with certain automotive parts (e.g. liners for the insides of pistons), cutting tools, advanced gas turbines, ceramic armour and aircraft jet engines amongst many others. At present a massive research effort is underway better to understand the fundamentals of the synthesis and processing of those structural, electronic and optical ceramic materials which are deemed most promising for future applications.

The fabrication techniques for ceramics include powder forming techniques, vapour deposition, chemical approaches and melting techniques. Currently a systematic approach for improving the properties and process controls of ceramic materials is underway.

The diffusion of advanced ceramic materials in the future will require a reduction in the cost of powders, further automation of the fabrication processes, reductions in the rejection rate and in finishing costs, and the development of new processing technologies.

The major markets for advanced ceramics are at present to be found in electronics, whereas structural applications have not yet fulfilled earlier expectations. The world output of electronic ceramics in 1992 was 428 million kg as compared to 125 million kg for ceramic coatings and only 29 million kg for structural ceramic applications. The average annual growth rate projected to 2002 for the world output of electronic ceramics is 4.6%, for ceramic coatings 1.7% and for structural ceramics 3.8%, according to the US Bureau of Mines.

ADVANCED POLYMERS

The tailoring of the molecular structure of polymers requires the development of new processing technologies in order to achieve carefully controlled microstructures and desired properties. The chemicals producers are not only further developing synthetic polymers, technical plastics, synthetic resins, fibres and films but are also engaged in the development of polymer alloys yielding materials with entirely new properties. Combining different polymers creates entirely new possibilities because of the resulting additional properties, and not surprisingly this has led to the application of the alloying principle, originally associated with metallurgy, to fibres, films and paints in many industrial laboratories around the world. Another major research area is in high performance polymers to satisfy the demands of the automotive, aerospace, electrical and electronic industries.

ADVANCED COMPOSITES

There are two main points about advanced composite materials. The first is that they are the natural choice where extreme performance requirements cannot be met individually by monolithic materials. The second is that, given that they can be tailored to meet specific needs, stress-strain distributions, temperatures and other conditions of use, they are destined to become the main structural materials of the future, displacing monolithic materials from many applications. New technologies are placing increasingly more stringent requirements for combinations of material properties that no single material can meet. In addition, mixing a matrix with a particular reinforcing agent can impart to the resulting composite material properties that neither material possessed on its own.

The choice of matrix material is determined by the temperature the material will be subjected to in use. Polymer matrices utilize thermoset plastics which cannot melt or epoxies made of a thermosetting material. Clearly the matrix that is chosen will dictate how the material is processed and fabricated. For a polymer matrix composite (PMC) the process is long. The fibres in the form of yarns or bundles are impregnated with the matrix resin and are then assembled mainly by hand or by the automated piling-up of many layers into a laminated structure. If the resin used is a thermoset the structure must be cured by a costly autoclave process, in which the material is often held at high temperature for several hours. PMCs possess light weight and high stiffness and stress in the direction of the reinforcement, and they are therefore used in aircraft, cars and other moving structures. But they decompose at high temperatures. Moreover, they are fabricated in a labour-intensive, though increasingly automated, process which is not suitable for high-volume, low-cost industrial applications. Before they can be commercially produced successfully their costs must be reduced, and the fabrication methods improved. In 1989 worldwide sales of PMCs reached US$4 billion according to the United States Aerospace Industries Association. The US Office of Technology Assessment, on the other hand, points to a figure of US$20 billion in annual sales for advanced composites by the year 2000. Such materials are critical for aerospace applications but will be increasingly diffused to the production of civilian aircraft and, possibly, to the car industry. The average annual growth rate for PMCs worldwide is estimated by the US Bureau of Mines to be over 6% per annum until 2002.

When the operating temperature is high enough to degrade a PMC, then a metal matrix composite (MMC) is considered. But metals have high density in comparison to polymers (hence aluminium, magnesium and titanium, the 'light metals' are most commonly used as matrices) and present severe processing difficulties. MMCs with the greatest potential are the powder metallurgy-based aluminium matrix reinforced with particulates, whiskers and platelets of silicon carbide, and the liquid aluminium-based matrix reinforced with semicontinuous alumina fibre preforms. MMCs face several difficulties. The use of high-cost raw materials and complex processing technologies result in significantly higher costs than competing materials. In addition, there is a tendency for the matrix-reinforcement bond to fail after repeated temperature cycles, and the interface can degrade due to reactions between the metal matrix and its reinforcement. Here again, improvements in processing technologies are critical for greater diffusion of MMCs in the future. MMC shipments globally are estimated to grow by an average of 9.3% per annum, mainly in automotive applications.

For situations in which the matrix needs to be as heat-resistant, lightweight, stiff and strong as the reinforcing material, ceramics are used. In contrast to PMCs and MMCs whose fibres are used to supply strength, ceramic matrix composites (CMCs) have fibres which block the growth of cracks and thus make the composite tough since it is already stiff and strong thanks to the ceramic matrix. Many CMCs grow tougher and hence stronger as the temperature rises. However, this very property makes processing difficult.

Another composite is the carbon-carbon composite (CCC) which can tolerate the highest temperature of any known composites. Both matrix and reinforcing agent are of elemental carbon. CCC retains most of its strength at 2 500°C, and is used therefore for the noses of space re-entry vehicles. There remain, however, serious barriers to faster commercialization, such as the reliable reproduction of CCC components and oxidation resistance at high temperature. CCC shipments worldwide are projected to grow by just under 5% per annum until 2002. A major area of application is in aircraft brakes.

OPTOELECTRONICS

Much has been made in recent years of the fact that we live in the information age. However, the information revolution, which encompasses computers and communications technologies, and now multimedia, is inseparable from the materials revolution. Electronic and photonic materials form the basis of systems of information and communication and the ever-increasing functional power of such systems. In order to achieve the present levels of function in the microelectronics and telecommunications systems, it was essential that electric signals first be generated and transmitted and then controlled, amplified and switched. Each such improvement was achieved with the assistance of entirely new materials or an improvement in processing technologies.

The information explosion and the need to communicate large amounts of data has led to the development of photonics, a process in which information is carried by pulses of light. The basis of this technology consists of a fibreguide of silica glass which transmits the emitted light pulses. This is a more efficient means of transmitting information than pulsing electrical signals along a coaxial cable. The materials used are compound semiconductors, such as indium-gallium-arsenide-phosphide for the light-emitting laser and ultrapure glass for the fibreguide. Already fibreglass has made a substantial contribution to long-distance telephone communications, as well as at the local level and even in connections between and within machines. Progress in photonics has been very rapid since the advent of the laser in 1958 and owes much to materials science and engineering, which has developed the compound semiconductors and ultrapure glass to make it possible.

The science of optoelectronics utilizes developments in solid-state physics which have made possible new ways of using electrons and photons. Optoelectronics grew rapidly in the 1970s with the development of the low-cost quartz optical fibre, followed by the double-heterostructure semiconductor laser, which facilitated continuous oscillation at room temperature. These breakthroughs led to major R&D in the field of optical communications, which is a principal application of optoelectronics. The pace has somewhat slowed as optical communication networks have generally spread into the infrastructure of developed economies. However, the cost of key elements in optoelectronic devices remains high, and efforts are under way to produce high-performance, low-cost components.

In the 21st century it is expected that optoelectronic devices (e.g. optical memories, displays, optical integrated circuits and holograms) will provide the foundations of many technological advances. Breakthroughs in optoelectronics are expected to make it a key 21st-century technology, together with electronics.

Optoelectronics forms the backbone of the information infrastructure of the world and national economies, with the largest impact so far being on telecommunications. Rapidly expanding low-cost, high-speed communication capabilities combined with the storing of masses of digitized sound and video lay the foundations of multimedia communication and the information superhighway.

Optoelectronics component markets are relatively small at present, mainly consisting of flat-panel displays for laptop computers. However, optoelectronics components are critically important for entire product ranges (e.g. CD players) which could not be built without them. Optoelectronics technology is therefore responsible for markets of around US$50 billion (in 1994), rising to over US$200 billion over the next 10 years. In the USA alone, annual sales of optoelectronic components (mainly displays) could rise to nearly US$50 billion by the early years of the next century and US$100 billion by 2013.

Multimedia

Multimedia applications, based on products such as interactive TV, CD-ROM and client/server systems, continue to grow and are having a large impact on the existing computer, telecommunications, mass-media, domestic appliance and entertainment industries. The Japanese Ministry of Posts and Telecommunications predicts that in Japan alone, by the year 2010, multimedia industries would generate 2.7 million new jobs and revenues of $1.23 trillion or about 6% of GNP, as compared to 1.9% in 1990. This would make multimedia industries three times larger than the current automobile industry.

Future photoelectronic integrated systems

Some researchers believe that in the 21st century microelectronics will combine with optoelectronics and result in photoelectronic integrated systems, which will most likely become the major method of information processing. Photoelectronic systems are likely to generate the largest commercial market in which optoelectronics will play a major part. Using light in such a system will result in high speeds, low power consumption, low noise and the ability to expand in three dimensions. Three-dimensional superparallel systems can be developed for use in ultra high-speed computers, neural systems and optical systems.

Photons have a high speed (that of light), low power and are ideal for fan-in/fan-out interconnections. They are excellent signal carriers. Electrons have the largest charge per mass and are the best carriers for logical operations conducted in high-density semiconductor integrated circuits. These properties currently provide the basis for progress in optical communications and microelectronics. However, in the future photons and electrons will be combined to provide a wide variety of new systems based on ultra large-scale optoelectronic integrated circuits, which will be the key hardware of photoelectronic systems in the next century. System fabrication will be achieved once we develop the technology to combine optoelectronic components with the appropriate electronic components.

Nanoelectronics

With increasing miniaturization, we are moving towards an era, just three generations from today's chipmaking technology, in which transistors will be too small to print on silicon. Devices will be measured in nanometres or billionths of a metre, and will have to be grown on the materials as clusters of atoms.

Researchers have recently been examining materials and devices which are constructed of layers only a single atom thick. If we are able to control very precisely the structure and composition of layers of materials one or two atoms thick, then we can engineer the electronic properties and characteristics we require. By packing even tinier transistors more closely together, researchers can increase the power and speed of circuits, thereby dramatically enhancing the performance of anything that uses integrated circuits.

A breakthrough in electronic miniaturization

On 25 October 1994 researchers at Toshiba Cambridge Centre and Cambridge University announced that they had developed the world's first process to make quantum-effect integrated circuits. This is comparable in importance to the invention of integrated circuits in 1958, which eventually led to the microelectronics and information revolution that has been gathering pace since the early 1970s. The Toshiba process would enable the manufacture of devices comprising millions of exceedingly small components, no more than 10 atoms across in all, on a single chip. The circuit components are so small that the electrons in them would behave as both particles and waves, as predicted by quantum theory, thereby enabling the circuits to switch much faster than on conventional chips. Miniaturization of electronic devices at this level would lead to computer memories and microprocessor speeds 500 times greater than today's silicon chips and one-five hundredth of the size. Although several laboratories have succeeded in making such microscopic components, the production processes have been very costly and slow. The Toshiba process, however, makes it possible to mass produce such components.

SUPERCONDUCTORS

The phenomenon of superconductivity entails the complete disappearance of electrical resistance as a material is cooled below some critical temperature (Tc). Until the end of 1986 superconductivity was mainly connected with the properties of metals, e.g. niobium and alloys, at temperatures approaching absolute zero (i.e. 0 on the Kelvin scale, where 0K = –273°C). But at these very low temperatures, only helium with a boiling point of 4.2K is liquid and can be used in cryogenic systems. Even then a helium-based cryogenic installation has itself to be cooled with liquid nitrogen (boiling point 77K), making it an expensive, complicated and cumbersome system for machinery application. The highest recorded super-conducting temperature was 23K for a metallic niobium-germanium alloy. This was improved by the IBM team, for which they won a Nobel Prize, by a mere 7K, using ceramic materials for the first time. Subsequently there have been discoveries of new ceramic materials successively achieving much higher superconducting temperatures. In May 1993 a mercury-copper oxide semiconductor was discovered with a Tc of 133K. In December 1993 it was reported that a bismuth system copper oxide was discovered in France with a remarkable Tc of 250K, very close to room temperature. As yet this has not been confirmed but has generated a new wave of interest around the world.

Why is superconductivity so important? First, the fact that superconducting materials cooled below their critical temperature allow electric current to flow with zero resistance means that there is no power loss and no heating along their length. Secondly, a material in a superconducting state can generate lines of intense magnetic flux and can therefore repel magnets: this is known as the Meissner effect. These magnetic forces are so powerful that they are capable of lifting a train off its track and propelling it at 550 km/h. Thirdly, superconducting materials possess electronic properties that enable electrons to jump instan-taneously between components, called the Josephson effect. This could form the basis of a new generation of portable supercomputers millions of times faster than current models. In addition, these properties also allow for the detection of very small changes in external magnetic fields, such as those generated by human brainwaves, and are utilized in SQUIDS (superconducting quantum interference devices) in medical diagnostics. Such devices are already in use, employing costly low-temperature superconductivity (LTS). However, HTS could make such devices available to all doctors in a few years' time.

The new superconductors operating above the temperature at which nitrogen becomes liquid can in themselves potentially transform technology but the real breakthrough would come should room-temperature superconductivity be discovered. The exploitation of such a discovery would truly revolutionize technology and lifestyles, making available efficient and loss-free electricity and leading, for example, to compact small motors and actuators which could be incorporated in household consumer durables, cars, machine-tool drives and power-packs, to replace aircraft hydraulic systems for example, and other unforeseen applications. But, given that there is a lack of theoretical understanding of superconductivity in metals, and even more so in the new materials, we cannot predict the exact arrival of ambient temperature superconductivity.

In the medium term the greatest gains economically are to be found in small-scale applications of high-temperature superconductivity, especially in various industrial machines and electronic devices. In the long term superconductivity is seen as potentially having a major impact on energy and electricity generation and power transmission and distribution, including superconducting generators, power transformers, energy storage, power cables and nuclear fusion devices. In addition, superconductivity is poised to play a major role in high-speed transportation systems, not only in terms of maglev/liner express systems, but also in sea and submarine propulsion and in space planes and stations, electromagnetic launchers and aeronautical and automobile applications. Superconductivity research and application will be inextricably linked to the solution of pressing energy, environmental and medical problems in the next century. Such solutions require a long-term persistent effort by governments and industry, with potentially great gains for the winners.

SMART MATERIALS

Smart materials are advanced materials that respond or react to the environment in which they operate. In order to respond a smart material must be able to receive information, process it, take a decision and act on it. An example of a smart material that can respond and adapt to a specific external stimulus is light-reactive glass. However, smart materials which can learn to respond and adapt to a set of complex and multiple external stimuli in the manner of natural systems are still on the drawing board. Nevertheless, they have great potential and considerable research is under way in Japan and, to a lesser extent, in the USA and more recently in Europe.

The functional properties and capabilities of smart materials are contained within a single material at the level of their atomic or molecular structure. The development of smart materials involves collaboration across the disciplines of solid-state chemistry, polymer chemistry and biomimetics (literally, mimicking or replicating the ability of biological systems to perceive changes, either in their own condition or the environment, and adapt accordingly). Smart materials with multifunction properties and long-term performance in service depend on future advances in materials synthesis, fabrication and processing techniques if they are to move beyond the laboratory curiosity stage. By contrast, smart structures are assembled from a number of heterogeneous parts and materials: they do not need to use intrinsically smart materials but can nevertheless be 'intelligent'.

Research into smart materials worldwide is going two ways. In the USA and Europe effort is in the direction of introducing new properties and functions into existing materials and incorporating them into smart structures. Much of the research effort and funding in the USA has been directed towards military applications. However, the aim now is to transfer them to civilian applications, for example the development of safer, more durable infrastructures for roads, buildings, bridges and piping. In Japan an entirely different approach is taken. Here researchers have taken several steps backwards and are developing smart materials from first principles, looking at the functions of materials in general and how these may be improved. By asking what part of a machine performs a human function the research drive is to bring the human element into part of the system. Smart materials now being developed in Japan are becoming capable of sensing their environment, differentiating between stimuli and responding to those that are relevant or important.

BIOMIMETICS

Scientists are also looking at nature for inspiration for the creation of many interesting and revolutionary new materials. The molecular architecture found in, for example, the abalone shell and insect exoskeletons provides the basis for creating new materials in high-technology applications. The shell of the abalone is a ceramic composite made of chalk possessing high strength due to the unique way in which its molecular structure is arranged. Using this as a model, and employing higher-tech materials, scientists have synthesized an impact-resistant tank armour, which is twice as strong as current man-made ceramics. The lightweight but strong exoskeleton of the horned beetle has provided inspiration for advanced composites for the space shuttle. This natural skeleton is a complex composite of intertwined fibres, themselves often composites, which permits the animal to breath through it, insulates it, is resilient and has sensing devices providing designed-in damage control. These properties are particularly useful in space planes.

NANOTECHNOLOGIES

The inexorable drive towards smaller and smaller devices is leading to an era in which atomic-scale devices will be both necessary and feasible. At present all technologies use large aggregations of atoms. However, our generation is the first not only to be able to see atoms through scanning tunnelling and atomic force microscopes, but also to begin to build miniscale structures in which individual atoms serve as building blocks. Nanotechnology is the logical consequence and ultimate destination of our quest for control and manipulation of matter. Ultimately, nanotechnology will make possible the creation of inexpensive cubic-centimetre computers which are able to process 10^{14} million instructions per second (MIPS) and are self-reproducing, or the creation of submicrometre industrial robots. In fact, nanotechnology has immense commercial, medical, aerospace and military potential, offering the prospect of an overall, precise and eventually affordable control of the structure of matter. The resulting products could be high performance, surprisingly low cost, energy efficient and reliable.

We are still far from a full realization of molecular nanotechnology and the requisite fabrication capabilities. The timescale envisaged for practical development is two to three decades, with early results in computers and molecular machines around 2010 to 2020, when current chipmaking technology runs out of steam. Nanotechnology will provide the foundation of all technologies in the next century. The impact on lifestyles, industry and the economy will be as great as that caused by the industrial revolution, only in a shorter timescale.

NEW MATERIALS AND CORPORATE STRATEGIES

Firms, industries (and nations) that produce and use materials must increasingly master and develop long-running strategic responses to crucially important developments underway in the materials field. Below we briefly highlight some of these developments.

Fundamental understanding of materials

A first priority is to continue to build up fundamental understanding of materials behaviour and its application in order to meet the emerging paradigm in the materials field by the late 1990s and the early part of the next century. Firms in aluminium, steel, nickel, manganese, chemicals, ceramics, glass and so on, in collaboration with public and academic research organizations at home and abroad, must develop capabilities to understand and quantitatively define and control the microstructure of a material and its relationship to the processing path and performance. These capabilities must then be applied to the integrated design of a material, the product or component and the fabrication process. Here mathematical *modelling* and *simulation* skills together with testing, evaluation and characterization skills, in-house and across the technology infrastructure, are crucial.

Getting close to the customer

The second priority is the need for materials producers to get close to customers in order to provide materials systems in functional and structural applications which are environmentally friendly, ecologically sustainable, cost effective and which meet the final product and manufacturing needs of these users. That is, materials producers must understand the needs of user industries (e.g. automobiles, aerospace, machinery, microelectronics and optoelectronics and so on) in terms of performance and manufacturing (e.g. in joining, forming or assembly techniques).

Building matter at the atomic and molecular level

A distinct trend in materials research is the progressive move to the atomic scale. Over the next 20 years materials producers will become increasingly capable of designing and creating customized materials from the manipulation and control of atoms and groups of atoms. As fundamental understanding, computational skills and simulations continue to make rapid progress, known materials will be greatly improved in terms of performance, and the R&D cycle will be dramatically cut. Moreover, new materials will be created from quantitative, physics-based approaches. The 2010s to 2020s will be the era of nanophase materials and nanophase processing technologies.

NATIONAL MATERIALS SCIENCE, TECHNOLOGY AND INDUSTRIAL STRATEGIES FOR THE 21ST CENTURY

Technical change across virtually every major field today depends critically on advances in materials. Existing conventional materials cannot meet the emerging requirements of high-technology applications. Thus, further progress in information and communications, surface transportation, aerospace, deep-sea operations, energy conversion and conservation, biocompatible materials and medical diagnostics, environmentally safe products and 'clean' technologies, biotechnology and the life sciences is constrained by the lack of appropriate materials.

Basic science underpins new technologies

More than at any time before, the basic sciences today are responsible for major technological breakthroughs and the provision of the knowledge base underpinning technical advance. Support for basic scientific research has therefore become a critical policy variable in debates over strategies to sustain technological leadership and devise appropriate industrial policies. We should note however that the relationship between science and technology today is complex, involving feedback mechanisms and the interplay of science push and market pull. Moreover, government and industry interact at all stages of the research, technology development and commercialization cycles.

The Clinton Administration in the USA has placed emphasis on orienting basic research to industrial needs and commercial applications. Moreover, it has unveiled ambitious new technology plans to improve US industrial competitiveness and develop next generation technologies through government-university-industry collaborative alliances, as in automobiles for the year 2003, liquid crystal displays, information technology highways and other areas currently under study by the Office of Science and Technology directly under the President.

It is widely recognized that Japan faces considerable difficulties in the conduct of basic scientific research. But these are not insuperable and it would be a serious mistake to underestimate the massive effort and resources that have been directed in recent years towards meeting the needs for creative scientific research. Scores of modern R&D labs have been constructed by many Japanese corporations, while internationalization and location of R&D facilities abroad enable companies to tap the world scientific knowledge base and recruit the best of local scientific researchers.

Recently Japan has decided to urgently double (to 1% of GDP) government spending on basic R&D and further to restructure its R&D system to reflect the greater importance today of fundamental research in high technology and the fact that the country has now reached the frontiers of technological advance. The 16 laboratories of AIST/MITI have been reorganized and new centres of scientific excellence are being set up. Since 1993 MITI's R&D system has been undergoing reorganization into the Industrial Science and Technology Frontier Programme (ISTF).

New technologies: a strategic weapon in global competition

A broadly based, of necessity, scientific research effort and the display of inventive creativity are all but irrelevant unless they ultimately lead to the development of useful technologies.

Irrespective of where new technological inventions originate, the most successful firms and industries are those which can incorporate them, fast and efficiently, into new innovative and commercially viable products and processes, achieving faster times to the market place than competitors. In a fiercely competitive global market, simultaneous or concurrent engineering tools enable firms to engage in an integrated and simultaneous product design and manufacturing approach, which, as a consequence, results in faster product renewal and continuous innovation. Faster product innovation, moreover, enables firms to incorporate the latest inventions and technological innovations into new, more sophisticated consumer durables or industrial machinery and equipment, and allows them to reach the market place in record time. Commercial and industrial success thus resides in those institutional mechanisms and design and manufacturing engineering capabilities that enable firms to apply technological advances to commercial ends. Technology is unquestionably a critical weapon for acquiring competitive advantage in the world market.

Emerging and critical technologies in the 1990s

In an important study submitted to President Bush in March 1991 (updated in 1993 and 1995), the US National Critical Technologies Panel (USNCTP) has selected 22 technologies deemed critical for military and economic competitiveness, which therefore require concentrated effort. The Panel stressed the need for US industry to adopt an integrated approach to both product development and associated manufacturing processes. Given the strong scientific knowledge base, the parallel concern is for the more effective translation of resulting technological advances into high-quality, high-performance, low-cost commercial products and military systems.

The 1991 and 1993 lists of critical technologies by the USNCTP are similar to lists of critical technologies published by the US Departments of Commerce and Defense in 1990 and 1991. Moreover, lists of critical, emerging technologies have been published in recent years by countries as diverse as Australia, Germany and Japan. And between 1991 and 1993 Germany collaborated with Japan to engage in a Technology Forecasting exercise using the Delphi method in 1 500 important technology fields. The UK also began a Technology Foresight programme in 1994, having studied the Japanese method. Several sectoral reports were published in the spring of 1995 and the first Report of the Technology Foresight panel which reflected the opinion of several thousands of UK experts was published in May 1995. R&D efforts must, of course, be made to develop the list of critical technologies identified. It is true to say that industrial leadership by the early 21st century will go to those industries and countries that have taken the lead in these core cutting-edge, next-generation technologies.

Public-private sector alliances

The USA has recently reorganized its R&D approach according to the Japanese model. The same is true for Chinese Taipei and the Republic of Korea. And the European Union's new Framework programmes show a distinct emphasis on commercial application. A crucial implication of the conditions in science and technology today is that a long-term, strategic approach is required. In many cases, the complexity, costs, risks and long time horizon involved imply that the private sector will not undertake the required effort. The development of next-generation technologies with large market potential, and which are necessary to meet social, medical, environmental and energy needs, requires long-term systematic and directed R&D efforts by firms, alliances between firms and collaborative programmes between private industry, government laboratories and universities.

Private industry can participate in joint public-private, long-term, risky materials R&D programmes but is also free to pursue its own long-term R&D objectives. Moreover, private firms can and must set up and pursue their own short- to medium-term commercially driven R&D and technology programmes. The two approaches are complementary and not mutually exclusive, and must not be confused.

Japan: from catching-up to pioneer in frontier science and technology in the 1990s

The promotion of new materials development and use forms an integral part of a long-term strategic approach to reorient Japanese industry towards high-technology and knowledge-intensive production. The role of new materials as underpinning technical change in all leading-edge technologies as well as conferring competitive superiority in manufacturing industry is very clearly recognized in both the private and public sectors. Advanced materials are therefore seen as being of prior, strategic significance to a successful reorientation towards high technology and the attainment of competitive superiority in the world market. Hundreds of Japanese companies entered the field of new materials in the mid-1980s, and the emphasis in recent years has been on commercialization of materials already developed and related to the existing technical strengths of the companies concerned. However, leading-edge Japanese corporations are maintaining and increasing their long-term R&D on core materials technologies necessary for the 21st century (e.g. Toshiba, NEC, Sharp, Nippon Steel). Smaller firms are concentrating on only a few or even on one advanced material with identifiable and more immediate market prospects.

A redivision of labour – globally and regionally

In recent years, a complex international and regional redivision of labour is emerging in which economies at different levels of industrial and economic development are shifting towards more sophisticated and higher value-added products and processes. Advanced industrialized countries in Europe, Japan and North America are moving towards higher value-added production employing advanced manufacturing technologies. They are closely followed by the newly industrializing economies such as Brazil, Mexico, Chinese Taipei, the Republic of Korea and Singapore. The latter three have announced plans to shift their economies to high technology, and to work towards fully industrialized economy status by the year 2000 (2030 for Singapore).

These are followed closely by second-tier newly industrializing and emerging economies, such as India, Thailand and Malaysia. Several other economies are now moving into the positions vacated by the second tier, and these include Indonesia, the Philippines, China and Viet Nam. The evidence clearly indicates that as economies restructure and shift to higher levels of technological sophistication they experience constraints imposed by the domestic availability of advanced materials, parts, components and devices. In many cases the requisite advanced components are unavailable from foreign sources that are competitors, or are prohibitively expensive, of inferior quality or unavailable on time. Hence a certain degree of domestic autonomy, independence and competence in advanced materials technologies are of the essence. Moreover, domestic suppliers and supporting and maintenance firms are also important in sustaining competitive local manufacturing activities and in attracting foreign direct investment in certain areas. Hence the importance attached by Malaysia and Thailand to the promotion of domestic parts and components production to deepen the industrial structure, support user industries and attract foreign investment of ever-increasing sophistication. The experience of the rapidly growing electronics industry in Malaysia clearly illustrates this tendency.

Emerging strategies in the USA

Several recent reports have laid special emphasis on advanced materials as being critical to US competitiveness and its ability to attain or maintain a lead in high-technology sectors. For example, the Panel on National Critical Technologies (1991, 1993, 1995) emphasized in particular the acquisition of materials synthesis and processing skills. Moreover the Panel placed special emphasis on the need for US industry to adopt an integrated and, thereby, continuous-improvement approach to both product development and the associated manufacturing processes to produce them. Given the strong US science base, the parallel concern of the report is the need for a more effective transmission of resulting technological advances into high-quality, high-performance, low-cost commercial products and military systems.

The critical significance of materials synthesis and processing is also stressed in the important report by the National Research Council, *Materials Science and Engineering for the 1990s*, published in 1989. This theme was echoed in the follow-up report of the Materials Research Society which evaluates the progress and requirements of implementing the Research Council's recommendations. The report makes the important, and in the US context the somewhat surprising point that the USA now needs to move towards developing a 'strategic, goal oriented planning approach to materials R&D, involving industry, universities and government laboratories'.

These two reports provided the key elements in preparing the federal programme in materials science and technology, which is entitled Advanced Materials and Processing Programme (AMPP).

In order to address the identified opportunities and needs, a multiyear, multiagency programme began in financial year 1993 in order to enhance the effectiveness of the federal R&D programme in Materials Science and Technology. The aims of the AMPP are to improve the manufacture and performance of materials and to enhance the nation's quality of life and economic growth. The AMPP will pay particular attention to the interfaces between universities, government laboratories and industry, and to the process of technology transfer from basic research to application. The AMPP is expected to add momentum to an evolutionary shift in US materials R&D. Whereas R&D was oriented towards modifying natural commodities to make useful technologies, research and development now increasingly concentrates on tailoring materials to achieve specific properties.

Strategies in the European Union

Within the European Union there have been sustained and intensified efforts to improve industrial and materials technologies since at least the mid-1980s. The emphasis is, at the moment, on identifying community-wide trends and needs in materials technologies and in creating the appropriate framework for the private sector to undertake market-oriented research and development. A recent comprehensive and in-depth study conducted on behalf of the Commission of the European Union examined the current state of industrial and materials technologies and the basic technological needs and development trends within the EU. The results indicate that the industrial and materials technologies are of paramount technological and economic importance for the EU and can support industrial competitiveness through the application of novel materials, advanced design and manufacturing routes and high-quality strategies. European-wide collaborative R&D programmes (BRITE/EURAM) have been underway since 1986 with important consequences for European industry.

Opportunities for mineral resource-rich economies

It should be clear that over 60 elements used in new materials derive from minerals. These include rare earths, zirconium, hafnium, bismuth, arsenic, cadmium, germanium, gallium, indium, thallium, selenium and tellurium. Some derive from limited domestic reserves in industrialized economies or are by-products of declining metals production. Hence economies such as that of the USA are experiencing constraints in advanced materials development and application due to a restricted supply of certain mineral resources and associated processing facilities. Moreover, the USA experiences considerable import vulnerability in certain minerals, while it has no reserve of caesium, osmium, rhodium, rubidium and ruthenium for use in advanced materials in electronics, energy and biomedical applications. New materials provide considerable opportunities for many resource-rich economies such as Australia, Canada, China, Malaysia, South Africa and Brazil.

Australia's determination to develop advanced materials capabilities, using local resources, specifically to develop materials technologies for mass markets (e.g. magnesium components for the car industry), while strengthening her manufacturing base and linking it to the basic research infrastructure, is richly instructive for other mineral-rich economies. Moreover, the removal of sanctions against South Africa led Japanese metal producers to invest in its mineral-metallurgical sector. Following the election of the ANC majority government in 1994, great emphasis is being placed on the development of South Africa's science and technology capabilities and on the mineral-metallurgical sector. Canada developed a strategy for advanced materials between 1988 and 1993, with the government playing a catalytic role within a market-oriented approach. No new funds are currently available and the government is reevaluating its strategy for more efficient R&D. At the same time advanced materials continue to be viewed as crucial to Canadian industry's growth into the next century. Many Canadian firms have engaged in R&D and the use of advanced metals, ceramics and polymer composites.

New materials and the socio-economic objectives of developing countries

The basic needs of developing countries with respect to housing, transportation, food packaging, water and energy distribution and health care can be met through more efficient utilization and upgrading of the domestically or regionally available natural resources, using scientific insight and new and improved technologies. The materials revolution affords opportunities to developing economies to make fuller use of domestic materials, while minimizing energy requirements and environmental disruption, and to develop advanced materials designed to meet their needs and conditions. In other words, advanced materials must be tailored to meet the specific requirements of industry and the infrastructure in developing countries. The new materials science and engineering base must be mobilized, internationally and within the developing world, to further development in the coming decades. For although the science base of the new materials is common throughout the world, the direction of application and problem-oriented R&D cannot exclude the pressing needs and available resources of developing economies.

CONCLUSIONS

Materials have now emerged as a science-based, knowledge-intensive, generic and enabling component of technology upon which progress in most other fields increasingly depends. Firms, industries and nations need to build a critical mass of data and expertise on materials science, engineering skills and infrastructure and systematically pursue selected R&D priorities. This will enable them to realize the potential of new long-term, coordinated and integrated materials and industrial strategies and to back them up with the relevant science, technology and information infrastructure, education and training programmes.

Recent research indicates that government, academia and industry interact at several stages of the innovation process. The domestic infrastructure links between the science base and industry and between networks of firms and people can be crucial for the competitive success of domestic firms and industries in the world market. Firms embedded in a national or regional science and information infrastructure can acquire cumulative advantages in specific technologies and industries. The conclusions of this point to the fact that the infrastructure of domestic materials science, measurement and testing is becoming crucial for the organization of R&D and the commercialization of high technology across the industrial base. Conversely, the promotion of high-level national science and technology and high-speed information flows, which facilitate research and innovation, can act as a magnet for the attraction of direct foreign investment and the location of production activities and R&D and design in domestic centres, thus providing cumulative advantages to the national economies in question.

A major problem for the next century will be the international division of labour as it affects newly industrializing economies and the large number of developing countries at different stages of development. Advances in science and technology (S&T) are by-passing nations, continents and regions. Such marginalization is likely to accelerate unless priority is given to the building-up of education, science and engineering skills and the creation of the appropriate technology and communications infrastructures in the large number of countries in danger of further marginalization in the world economy of the next century. Many policy makers at national and international level will view the developments described in this chapter as far-fetched, too remote or irrelevant to the needs of development. However, this is a dangerous and ill-informed view. Developing economies need to participate and share in the fruits of the dramatic advances in the science bases of the technologies involved in materials, life sciences, agriculture and information, which can be directed to meet many of their domestic basic needs and growth objectives.

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Mr Kaounides is a recognized international authority on mineral economics and the role of advanced materials in business strategies, global competitive advantage and trade and growth in manufacturing and high-technology industries. He is senior consultant to UNIDO, Vienna, in the areas of new technologies and science, technology and industrialization strategies for developing and newly industrializing economies. In addition, he has acted as consultant to the Economist Intelligence Unit in London and several other international organizations, and has been a Research Fellow at the University of Sienna and a Visiting Fellow at the IDS, University of Sussex. He is currently working on national and corporate strategies in advanced materials technologies for the *Financial Times*, London.

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3

THE GENDER DIMENSION OF SCIENCE AND TECHNOLOGY

The conceptual framework

SANDRA HARDING AND ELIZABETH McGREGOR

The gender dimension describes the way in which culturally organized differences between men and women interact with historically and socially diverse scientific and technological practices and their meanings. Scientific and technological cultures and practices shape gendered social relations and, in turn, are shaped by them (see Collins, 1991[1]; Connell, 1985; Cook and Fonow, 1991; Harding, 1986, 1987, 1991; Harding and O'Barr, 1987; Lorber and Farrell, 1991; Zuckerman *et al.*, 1991). Thus the science and technology (S&T) that each culture has are a consequence, in part, of local and global gender relations, and each culture's gender relations are the effect, in part, of past local and global S&T changes.

To the extent that women and men want to know different things about how nature works, they will tend to ask different questions and generate different scientific projects – projects that, like all scientific projects, can be pursued by both women and men. The conceptual framework here draws on the resources of two decades of gender studies and at least three decades of the history and sociology of S&T in the North and the South. Two central themes in these studies that are important for understanding how gender relations interact with S&T institutions and projects can be briefly summarized.

GENDER DIFFERENCES

Although men and women are biologically different they are much more like each other than popular culture would often have us believe. But how humans think about biological differences, how they assign social activities based on what they perceive to be such differences and how S&T projects impact differently on women and men vary from culture to culture. Gender is this social contribution to the relationship between men and women. All too often, gender is assumed to be just a way to refer to women, or to the distribution of women and men in, for example, universities, sciences or other social units. However, this usage obscures other important aspects of gender relations such as the social meanings of manliness and womanliness and, most importantly, the ways in which men's or women's culturally different interests and values structure particular social activities, organizations and projects – including scientific and technological ones.

Women and men tend to have some distinctive interactions with nature because of their differing biologies, but also because they are assigned different social roles and activities, and thus have different interests in, needs from and hopes about how nature 'works' and the resources and dangers it provides. Moreover, evidence suggests that women tend to organize their laboratories and other work projects in somewhat different ways from their male peers and, of course, how scientific projects are organized has an effect on what we end up knowing about nature's processes. Relevant here are numerous studies on how organizations are gendered (Acker, 1992; Kanter, 1977; Mills and Tancred, 1991).

Thus, gender-differing interactions with nature are assured by differences in biology, in social presuppositions and interests, and in the organization of the production of knowledge. For these reasons, scientific and technological changes will have differing impacts on women and men in any culture or subculture. Moreover, to the extent that women are excluded from defining what science and technology should concern themselves with, what a culture knows about nature will disproportionately represent men's interests, needs and hopes.

Valuable insights can be gained by asking the following question: if the assignment of gender roles in S&T projects were reversed, how would our knowledge of nature be different? In many research areas it probably would not differ at all; but in many others, it is likely to do so. It would be useful to consider and

1. References cited in the chapters that follow will be found in the main References and further reading, p. 345.

study how scientific and technological priorities and representations of nature might change if women were to direct national health institutes, environmental regulatory agencies, regional agricultural policy, projects to eradicate poverty and, generally, if they were more represented in policy making in governments, science and multinational corporations.

SCIENCE IN TECHNOLOGY; TECHNOLOGY IN SCIENCE

While it is sometimes easy to extract the purely scientific from the technological aspects of issues, such a separation is often unproductive. Scientific projects frequently originate in social needs that have been defined as technological and, then, as scientific problems – whether or not this is the best way to think about them. For example, poverty in both developing and developed societies has often been described as being caused by overpopulation. Poverty reduction is then thought to require such strategies as sterilization and better contraception, both of which, initially, require scientific research.

Of course, there are many other reasonable explanations of poverty that lead to solutions that may or may not require scientific research. For example, as the 1994 UN International Conference on Population and Development report recognized, it now appears probable that poverty *causes* overpopulation, rather than the reverse, since poor families often perceive children to be a potential economic resource for increasing family income and providing for parents in sickness and in old age. Moreover, increased education for women appears to be the single most effective way of lowering birth rates.

Scientific change often requires and/or follows upon the development of distinctive technologies for gathering data about nature. Modern science, with its reliance on manipulating nature through the experimental method, is technological at its very core. Moreover, the availability of scientific knowledge routinely results in technological changes that were the purpose of the scientific research in the first place. Of course this is the case with, for example, medical and environmental sciences. More generally, basic research is allocated only a fraction of the funds supporting scientific research and development, and even the selection of which part of nature to explore through basic research does not occur separately from cultural traditions or contemporary social interests. Different cultures might well make different choices.

Thus science and technology are more usefully conceptualized as including their cultures and practices. We can understand neither nature nor the histories and present practices of S&T if we do not identify the historical practices and cultures that different societies developed in order to learn more about the parts of nature that interested them. For example, the mechanistic metaphors and models of nature that were so valuable to early modern European scientists carried class and gender meanings for them and their culture. These meanings helped to shape the patterns of European expansion to which these modern sciences contributed. Insofar as they link culturally local ideals of 'civilization' and of manliness to success at dominating nature (and people's 'natures'), they remain today an obstacle to wiser environmental science and management policies (Lloyd, 1984; Merchant, 1980; Seager, 1993; Shiva, 1988). In many ways nature is indeed like a machine, and in other ways it is not at all like one. Now we can usefully ask what laws of nature were made invisible or obscured by long reliance on only this one model of nature.

These wider ranging understandings of gender and science in society enable more accurate and comprehensive accounts of the gender dimensions of science and technology.

Science by whom?

ELIZABETH McGREGOR AND SANDRA HARDING

Where are women in science and technology in 1996? Are women acquiring science and technology education, obtaining credentials, winning jobs and achieving promotion at a rate equivalent to that of men? Information that would answer these questions is scarce, fragmented and difficult to evaluate, although it is clear that in most countries women are under-educated, have fewer credentials, are under-employed and clearly under-promoted. Are women scientists and technologists participating in regional, national and international decision-making and advisory groups? Here it is easy for even a casual observer to confirm that women's presence is negligible in virtually any S&T policy groups.

The full extent of this under-representation remains somewhat obscured in the absence of complete and comparable data. Until attention is given to the systematic collection of disaggregated data at the institutional, national and international levels, equity issues will continue to remain relatively invisible in S&T communities.

OUTSIDE THE FORMAL SYSTEM: ISSUES OF LITERACY AND ACCESS

From the outset of their lives, girls frequently experience unequal access to opportunities in education because of socio-economic and cultural obstacles. Only those able to scale these initial barriers will eventually 'enter through the school door' and become part of the early pool of talent available for recruitment into S&T.

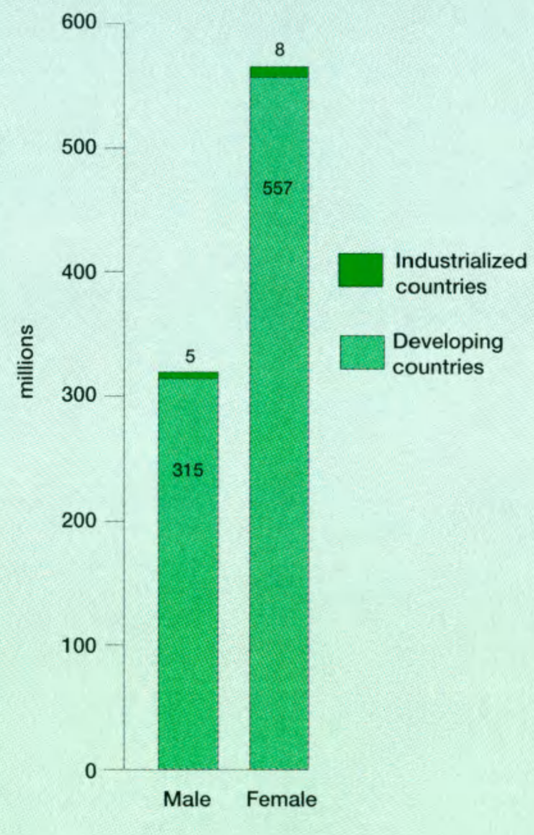
According to UNICEF reports, some 30-50% of children in developing countries never enter the formal school system and a disproportionately high proportion of these are girls. Over 100 million children of school age worldwide fall outside the school system, and 60 million of these are girls. Figure 1 illustrates that currently almost two-thirds of the world's illiterate are women and Figure 2 provides evidence that boys have preferential access to schools in many parts of the world.

Exclusion from literacy training and from general science education available in schools limits equal access to the information and knowledge necessary to make informed decisions about S&T matters in public policy and in everyday life.

These realities underline the urgent need for policy attention to address literacy for all with specific programmes to eliminate the gender gap.

FIGURE 1
ESTIMATED NUMBER OF ILLITERATES AGED 15 AND OVER, 1995

World total 885 million



Source: UNESCO, *Statistical Issues*, October 1994, STE-16, Table 3.

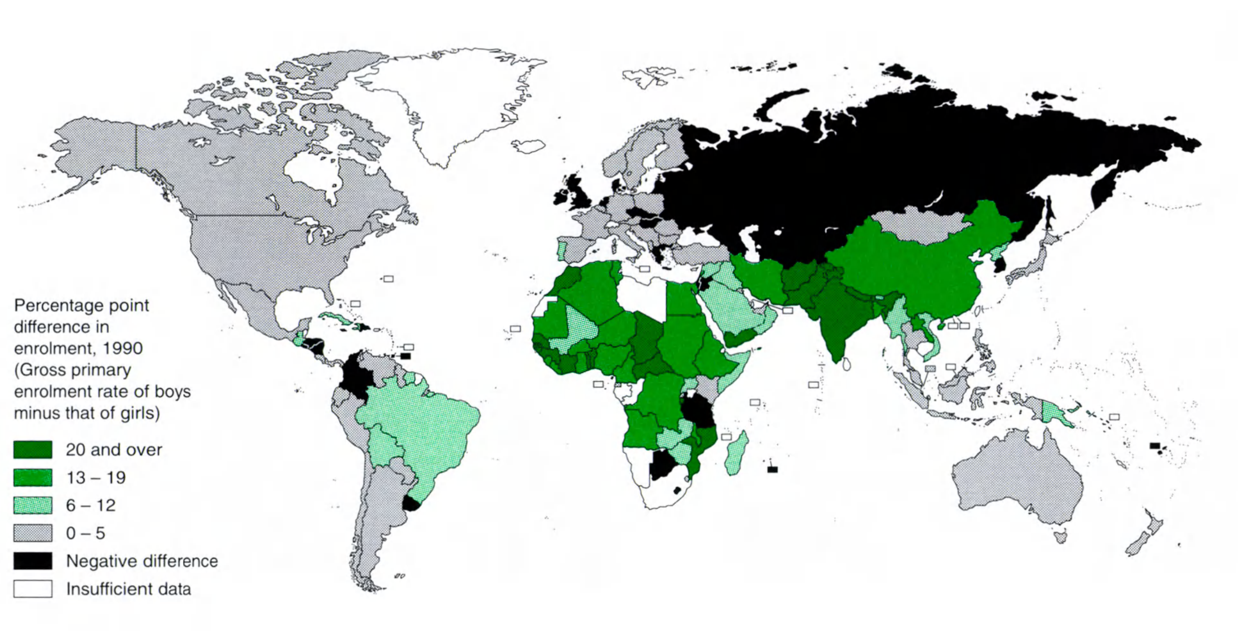
Promoting S&T literacy through informal education

While governments must be compelled to ensure universal education for all, parallel efforts are required to reach those currently outside the system, through both governmental and non-governmental organizations, to support S&T literacy in the informal sector, paying particular attention to closing the gender gap in global literacy rates. For example, in 1993, the Declaration of the International Forum on Scientific and Technological Literacy for All (Project 2000+), convened by UNESCO and its partners (notably, the International Council of Associations for Science Education), called for a programme of regional and sub-regional cooperation between countries with the objective of focusing on S&T literacy for all with particular policy attention to girls (UNESCO, 1993).

In 1993, the Expert Group Meeting organized by UNIFEM (United Nations Development Fund for Women), issued its report *Women, Science and Technology: New Visions for the 21st Century*, urging governments to promote programmes to repackage and make available scientific and technological knowledge to women at all levels of society (UNIFEM, 1993*a*).

Emphasis on practical technical training for women was also identified as an important strategy by developing country participants in a workshop convened by the National Research Council Board of Science and Technology in International Development (BOSTID), Washington, 1994, entitled Barriers Faced by Developing Country Women Entering Professions in Science and Technology. This workshop stressed the need to shift the emphasis of informal education towards the training in technical skills necessary for science-based income generation for women (BOSTID, 1994).

FIGURE 2
THE GENDER GAP IN PRIMARY SCHOOLS



Source: UNICEF, UNESCO and WHO in World Resources Institute, *World Resources 1994-95*, New York, Oxford: Oxford University Press.

No data, no visibility No visibility, no priority

The way in which data in science and technology are predominantly collected renders women and their issues relatively invisible. At least two sets of data are essential for decision makers: data on women's participation rates in scientific education (by discipline), in S&T careers and in policy decision making; and data on the differential impact of S&T on the lives of women and men. Moreover, in the last two decades, there has been no shortage of recommendations calling for the systematic collection of disaggregated data.

The World Plan of Action for the Implementation of the Objectives of the International Women's Year in 1975 and the three UN Conferences on Women in Development (Mexico City 1975, Copenhagen 1980 and Nairobi 1985) all recommended strengthened coordination and consistency at national and international levels in the collection of statistics on women. The General Conference of UNESCO, at its 20th session in 1978, also proposed the collection of statistics on women for scientific and technological projects as well as on personnel. The World Conference on Agrarian Reform and Rural Development (FAO, 1979) requested governments to revise procedures for the collection and presentation of statistical data for the identification of women's participation in productive activities. The 1986 and 1989 UN World Surveys on the Role of Women in Development, and the 1990 UNDP *Human Development Report*, all called for disaggregated data to reflect the contribution of women to the global economy and to development. Further, the United Nations Conference on Environment and Development (UNCED, 1992) called for the quantification of women's work.

Twenty years on from the World Plan of Action these issues remain pressing and relevant and they appear in the text of the Platform for Action of the UN Fourth World Conference on Women (Beijing, 1995).

Despite these repeated calls for action, there persists a scarcity of disaggregated data. However some efforts towards progress should be mentioned:

- **Internationally**, the *UNESCO Statistical Yearbook* remains the single most extensive source of country-specific data on school enrolments for girls. In 1986 the UN Statistical Division's *Compendium of Statistics and Indicators on the Situation of Women* included data on women in relation to science and technology. The Division devoted a section to women in science and technology in the 1995 publication of *World's Women*.
- **Regionally**, three recent workshops held in Asia (Mainstreaming Women in Science and Technology, Approtech, 1993), Africa (Science in Africa: Women Leading from Strength, AAAS, 1993) and Europe (Women in Science, European Community, 1993) have provided regional data on participation rates of women in science and technology.
- **Nationally**, several governments have assembled data and articulated a range of recommendations to create enabling environments for women (see the Canadian Prime Minister's National Advisory Board on Science and Technology publications *Winning with Women in Trades, Technology, Science and Engineering* and *Participation of Women in Science and Technology*, (Canada, 1993 and 1988); the UK report *The Rising Tide* (United Kingdom, 1993*b*); and the Australian report *Women in Science, Engineering and Technology* (Australia, 1994)). Some scientific associations are also assuming leadership in the analysis of gender issues in the profession (see the 1992 Canadian Committee on Women in Engineering's study *More Than Just Numbers*).

Yet data collection remains sporadic and unsystematic and suffers from a lack of consistency in methodology from country to country. This situation requires urgent redress at institutional, national and international levels.

Creative examples of initiatives in the informal sector include that of the Science and Technology Roadshow in Botswana. This project was supported by the Education Programme of the Commonwealth Secretariat and UNESCO, and sponsored by embassies, local companies, schools and communities. Travelling vans visited towns and villages bringing resource libraries and role-model videos. Workshops were held to train local women in technical and mechanical skills and a media logo and motto were designed to raise public awareness. As another example, in the People's Republic of China, the All

'In the Field'

Global research on women's technical innovations and local knowledge systems

Internationally, a series of field studies have highlighted the gender dimension of local knowledge systems.

- A special edition of the ***Indigenous Knowledge & Development Monitor,*** December, 1994, dedicated its theme to gender and indigenous knowledge systems (fax: 31 70 4260329, the Netherlands).
- **Do It Herself,** a project coordinated by the Intermediate Technology Development Group (ITDG) has conducted research on four continents to identify and strengthen women's contribution to technical innovation at the community level (fax: 44 1788 540270, UK).
- **WedNet,** supported by Canada's International Development Research Centre (IDRC), has conducted extensive research on women's local knowledge in natural resource management in Africa and is extending its research into Asia (fax: 254 2 562175, Kenya).
- **From the Ground Up,** a study in sub-Saharan Africa and Latin America, works from the assumption that while there are tremendous environmental dilemmas facing developing countries, there are also numerous illustrations of effective efforts in rurally based and locally generated resource management systems. The project seeks to identify communities involved in ecologically sound self-development with the goal of analysing these successes for other communities. The World Resources Institute is examining the gendered nature of this knowledge in a series of case studies (fax: 1 202 638 0036, USA).
- **ECOGEN,** coordinated by Clark University and the World Resources Institute in Asia, Africa and Latin America, also works towards an understanding of gender issues in natural resource management (fax: 1 508 793 7201, USA).
- **Our Hands – Our History** is a global field study in which The World Women's Veterinary Association with the Inter-American Institute for Cooperation on Agriculture (IICA), FAO and UNIFEM are exploring women's knowledge systems in animal health and crop production in Africa, Asia and Latin America. An accompanying guidebook, *Indigenous and Local Community Knowledge Systems in Animal Health and Production Systems – Gender Perspectives*, contains key policy issues, a synopsis of the literature, UN official documents and a directory to global networks (fax: 1 613 594 5946, Canada).
- **Bean Breeders in Rwanda,** a project of the Consultative Group on International Agricultural Research (CGIAR) is breaking conventional patterns of relations between agricultural research centres and farmers by collaborating specifically with women, and by testing improved bean varieties collaboratively with women as local crop breeding experts (fax: 1 202 334 8750, USA).

Women's Federation coordinated a five-year national campaign to bring literacy and technical training to millions of rural women (GWG-UNCSTD, 1995*b*).

Local knowledge systems

An important issue falling outside the institutionalized S&T system is that of local knowledge systems (LKSs) and their gender dimension. Generated and transmitted by communities over time, LKSs are gendered in that men and women often develop different skills and knowledge in response to socially and biologically assigned roles, which together create a knowledge system specific to local conditions, needs and priorities (Hill and Appleton, 1994). Women in particular may hold and transmit over generations the knowledge of agroforestry practices, plant and animal diversity, breeding, healing, harvesting and processing techniques and integrated resource management strategies. Yet, for the most part, development efforts have focused on incorporating 'modern' science approaches and technologies into development policies and programmes (GWG-UNCSTD, 1995*a*).

The UNIFEM Expert Group Meeting addressed the importance of local knowledge systems and drew policy attention to issues of appropriate acknowledgement and protection of these knowledge systems and their gendered nature:

> 'While most women practice S&T every day of their lives, they are considered (and consider themselves) as being technologically illiterate. When local technical knowledge is recognized as having value, local communities and especially women, lack the negotiating skills required to prevent exploitation' (UNIFEM, 1993*a*).

Cultures that ignore or devalue these other knowledge systems and the gender-specific dimension of scientific and technological change, deprive themselves of a rich source of experience and understanding and thus unnecessarily generate systematic ignorance that disadvantages every member of the culture. The UNIFEM Expert Group recommended highlighting the role of women's traditional food cycle technologies and the documentation on the merging of traditional and modern science within commercial contexts. The Expert Group report also recommended developing mechanisms to link women scientists with grassroots women (e.g. Ghana Association of Women Scientists).

INSIDE THE FORMAL SYSTEM: A CHILLY CLIMATE

Inside science and technology communities women encounter an array of overt and covert obstacles which cumulatively create a 'chilly climate' and result in an unwelcoming environment. These barriers militate against the full and equal participation of women in S&T and lead to women avoiding these domains or opting out in increasing numbers at higher levels of education and in the workforce. Discrimination on grounds of class, race and ethnicity creates additional barriers to minority women's entry, retention and promotion in science and technology.

Beginning in the home

In the home, parental attitudes can change the choices children make and unintentionally undermine girls' confidence, self-image and aspirations. Societal stereotyping, transmitted through parents, can convey strong messages to girls to avoid technical or scientific subjects as unsuitable for women. Furthermore, parental decisions to send only boys to school or apply pressure on girls to marry early and bear children can severely compromise the opportunity for girls to enter and continue in school.

In the educational system

In the classroom, teacher bias and behaviour can impact negatively on the self-confidence and subsequent performance of girls. Such bias can predetermine a teacher's different expectations of female students. Pamela Fraser-Abder describes this 'Pygmalion

Syndrome' of differential treatment based upon expectations, which in turn affects student achievement in the book entitled *Missing Links: Gender in Science and Technology* (GWG-UNCSTD, 1995*a*).

Furthermore, teacher assessments of student performance have been shown to change depending upon the gender of the name of the student appearing on the cover of the paper. In similar studies, where department chairs have been asked to rank applicants for the position of associate professor, the ranking of the applicant dropped significantly when the name was changed from male to female on the same application (Hall, 1982).

Exclusionary language in textbooks and lectures, reinforced by illustrations which emphasize almost exclusively the role of men in science, serves to project and perpetuate stereotypic images and biased behaviours. A World Bank Discussion Paper, *Women's Access to Higher Education*, noted that the nature and practice of S&T projects a masculine image, not only because men still dominate the field, but also because men dominate the language and images found in scientific literature (DePietro-Jurand, 1994).

Science curricula can also contain bias in content and focus. It is important to relate S&T in the classroom equally to the life experiences and issues of concern to girls. This is particularly the case in rural areas in developing countries, where the roles and responsibilities of girls and women differ significantly from those of boys and men. Women play the pivotal role in agroforestry and natural resource management and are most frequently solely responsible for the household's subsistance food production and the food security of the family. They are also usually responsible for the health management of three generations. Their focus, concerns and health issues are often distinct from those of men. Should we be surprised that girls and women are less enthusiastic about entering and remaining in sciences, where issues of concern to them and relevant to their life experiences remain relatively invisible?

In science communities and in universities, research on gender issues in science is only recently emerging as a legitimate activity. In academia, tenure review committees often discredit research on women's concerns, publications in women's studies journals, achievements recognized by women's scientific organizations, or scholarship using unorthodox methodology and paradigms. Female professionals in the sciences are not yet given adequate compensation for the substantial effort required to serve as role models and mentors. Furthermore, women professional scientists are frequently called upon to represent the 'women's view', rather than to give their professional opinions. When expressed, their viewpoints are often given less weight. Taken together, this results in the paradox of 'over-attention/under-attention' (AAC, 1986).

In S&T development and transfer

Gender bias in resource allocation towards issues of concern and relevance to men continues in many cases beyond the curriculum and into the public research agenda and S&T development. Gender issues in S&T are still not systematically addressed by governments and research institutions; priorities are set and resources are allocated without adequate consideration of the gender dimension. This was a finding of the Gender Working Group of the UNCSTD which concluded that most technical change appears to have been oriented to the tasks that men perform and to men's interests and needs in the development process.

Grassroots organizations similarly stress the missing link between women's needs and interests and the science and technology agenda.

In the workplace

In the workplace, a series of visible and invisible barriers and behaviours militate against women entering, staying and excelling. 'Micro-inequities' have been identified in the literature as those exclusionary behaviours that are often so small that they go unnoticed yet cumulatively create a chilly climate discouraging girls and women from entering and staying in S&T.

'Micro-inequities refer collectively to ways in which individuals are either singled out, or overlooked, ignored or otherwise discounted on the basis of unchangeable characteristics such as sex, race or age... Micro-inequities often create a work and learning environment that wastes women's resources, for it takes time and energy to ignore or to deal with these behaviours.' (AAC, 1986).

Unlike formal barriers, these informal traditions and practices are less obvious and harder to recognize. For example, women are assigned to less powerful committees, have fewer budgetary resources, have a harder time accessing support services from staff and are placed in less centrally located offices; they lack access to 'old boy networks' of institutional information and feed-back and do not have an equivalent pool of available mentors or role models to draw upon for advice and support. Attitudes can also interfere with objective and impartial interviewing techniques. Women's actual or potential marital and/or parental status may be raised in admission interviews. In contrast, men are rarely asked questions about how their family life would be affected by their careers.

Distinctive communication patterns and working styles of women and men are also the subject of several studies. Men tend to engage in highly assertive, impersonal and abstract speech forms and tend to prefer competitive interchanges, interrupt other speakers (especially women), control the topic of conversation and use gestures that take up physical space. Women, in contrast, use more personal and cooperative communication styles. They tend to make direct eye contact for longer periods of time and use gestures which express attentiveness or give encouragement (AAC, 1986). Researchers are currently beginning to explore the possibility that some features of 'women's speech' and working style might have positive values in fostering a more equitable scholarly climate based on the cooperative development of ideas (Hall, 1982).

Perhaps the most frequently reported barrier to women in science and technology – as in many other areas – is the challenge of combining career and family. Women who give priority to child-bearing and child-rearing during periods critical to career development and promotion within the current reward systems suffer the career consequences. Where men and women do not equally share childcare and household work it is frequently women who sacrifice their education and career opportunities for the home and family. Such choices – so long as society and S&T institutions do not recognize and value them – will result in lost opportunities to advance careers and compete for tenure or overseas scholarships and a loss to the S&T community.

Disparity in salaries for equivalent work also disadvantages women in science. Several studies confirm the reality of a gender gap in salaries (BOSTID, 1994; Australia, 1994). Lack of support for spousal employment is an additional issue for highly qualified women, since spouses of professional women usually have equivalent academic qualifications and are therefore less likely to be flexible in job relocation. Furthermore, promotions and tenure for women do not seem to be keeping pace with increases in enrolments, which has a dampening effect upon women's aspirations and expectations.

Finally, a central factor creating a chilly climate in the sciences for professional women is their isolation in a male-dominated domain. Efforts to bridge this isolation and provide peer support have resulted in the formation of several regional and global networks over the last two decades (see p. 340). In technical and vocational fields, a network of 16 African countries founded the Commonwealth Association of Polytechnics in Africa (CAPA) in 1978 to address issues relating to the integration of women into the development process through technical education and training. In Canada, the Women in Trades and Technology National Network, founded in 1994, promotes and assists in the recruitment, training and employment of women in trades, technology,

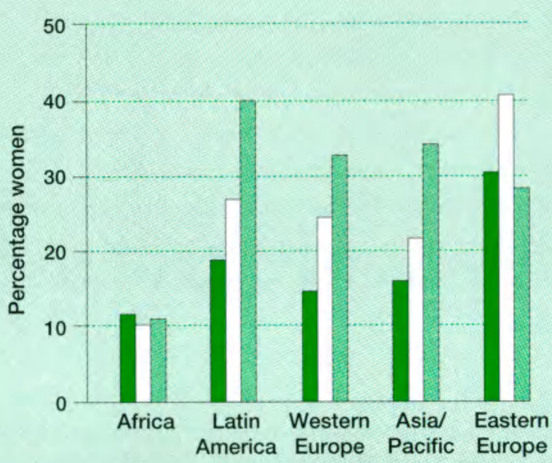
Global gaps and trends

Despite the dearth of complete and comparable data discussed earlier, and the significant complexity of cross-cultural comparisons, some general gaps and trends can be gleaned from available statistics to stimulate reflection.

IN S&T EDUCATION AND ACADEMIC CAREERS

- There is gender inequity in access to schools and in enrolments in science and technology, particularly at the tertiary level and in vocational schools. This situation is by no means improving steadily in all disciplines or in all regions. Industrialized countries do not necessarily have the best rates and data suggest that countries in transition are experiencing a decline in women's participation.

WOMEN IN S&T TERTIARY EDUCATION



Source: GWG-UNCSTD.

- Where science is a part of the core school curriculum and not optional, women pursue science careers in greater proportion.

- There exists a phenomenon of 'gender tracking' or the concentration of women in particular disciplines, and the difference between industralized and developing countries is relatively small.

- In academic careers, men far outnumber women and this disparity is more pronounced in older industrialized countries; the 'tenure track' is a 'slippery slope' for women professionals, with disproportionately few women achieving tenured status.

WOMEN IN PHYSICS FACULTIES IN UNIVERSITIES, SELECTED COUNTRIES, 1990

Source: Megaw, J. (1990) in Barinaga, M., *Science*, 263 (1994).

THE GENDER DIMENSION OF SCIENCE AND TECHNOLOGY

IN SCIENCE AND TECHNOLOGY EMPLOYMENT

- Women's participation rates are higher in government and public research and development agencies than in the private sector, but in both cases the under-representation of women is pronounced.

- Women professionals are not present in science and technology either in 'critical mass' or at a 'critical level' in national governments or in the United Nations or any other regional or inter-governmental body.

- As the status, remuneration and recognition of professions originally considered feminine increases, so access to them becomes more difficult for women and men move into the field; conversely, as the status of a field declines, men abandon it for more lucrative and prestigious work.

- The hiring, promotion and appointment of women in S&T lag behind increases in female enrolments and professional experience; and gender disparity in pay for equivalent work persists.

IN S&T DECISION MAKING

- The presence of professional women is negligible in decision-making bodies, high-level advisory boards and national academies.

- There appears to be a 'glass ceiling' for women in science and technology decision-making bodies – the higher in the system, the fewer the proportion who are women. This phenomenon cannot be attributed only to a smaller supply pipeline. Appointments are not keeping pace with increased numbers of professional women candidates with experience.

operations and blue-collar work. Electronic mentoring is another creative example of networking among women in S&T. The Systers Network for female computer students and faculty covers careers advice, peer support and electronic networking (see also p. 343).

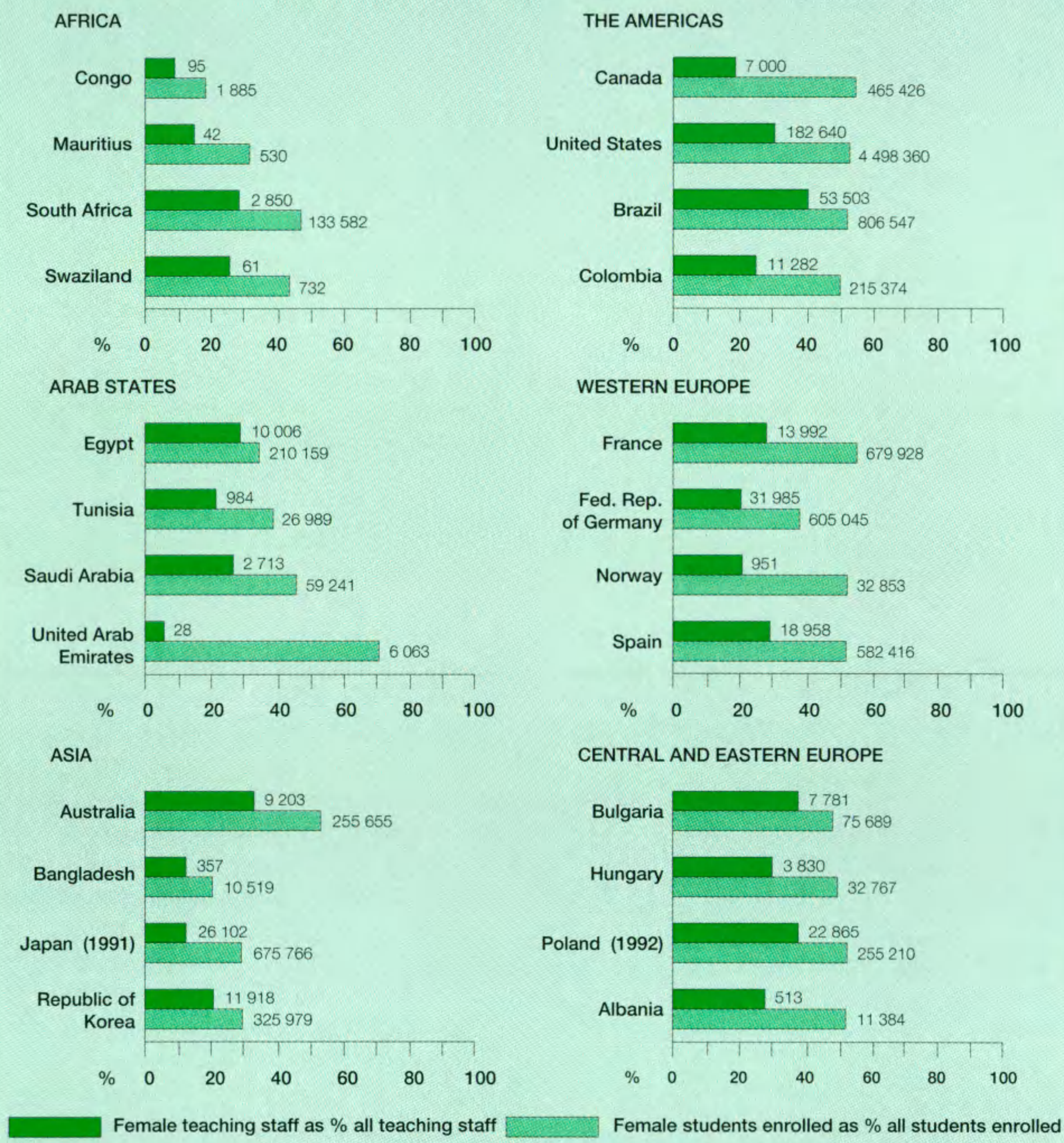
The costs of being the first

Would women make a difference to science and science decision making anyway – even if they were present in significant numbers? The paradox of critical mass has been recently described in the literature (Etzkowitz, 1994) in a study entailing over 200 interviews. The analysis addresses the apparent paradox that in some fields where a critical mass (defined as 15%) of women professionals in a faculty has been reached, the expected effect and qualitative changes anticipated were not realized. Interviews with women who have 'made it' in science find some women disclaiming any discriminatory barriers in the field. This phenomenon was examined and is explained by the authors in terms of a 'gender-generational fault line'.

Evidently, peer pressures to conform have especially powerful effects on the first members of a new social group to enter a workplace. For many senior female scientists today, the price of admission to careers in the sciences has been imitation of the values and working styles of their male colleagues. This is not to say that the accepted models are necessarily undesirable ones, but only that they may not always include those that enable younger women (and men) to make their greatest contributions to scientific research. In the study reported, fear of stigmatization led some of the senior women to deny the existence of gender-related obstacles, even when faced with irrefutable statistics documenting them. Younger female scientists expressed a significant difference in desired working styles and values from those women who were first to enter a field or workplace. Such studies suggest caution in generalizing from the responses of a few individuals or even just one age cohort to the preferences of women in science more

FIGURE 3

UNIVERSITIES AND EQUIVALENT INSTITUTIONS: FEMALE TEACHERS AND STUDENTS, SELECTED COUNTRIES, 1990



Note: Figures at the ends of bars are the actual numbers of females.

Source: UNESCO, *Statistical Yearbook 1994*, table 3.12.

generally: women in different career cohorts face different obstacles to full expression of their potential contributions to the sciences.

THE LEAKY PIPELINE

Efforts to 'add women into the S&T pipeline' have met with the reality that once inside the formal S&T system, a notable proportion of girls and women opt to leave. Attrition and underemployment of highly trained personnel is an extremely wasteful and expensive phenomenon to society. For example, the difference between female student enrolment rates at universities and the female component of their teaching staff is striking if all subjects are taken together (see Figure 3). Even in those countries with a good record of addressing gender issues, the figure can be surprisingly low; for example, in Norway only 9% of professors in higher education are women. The disparity with regard to S&T is even more significant.

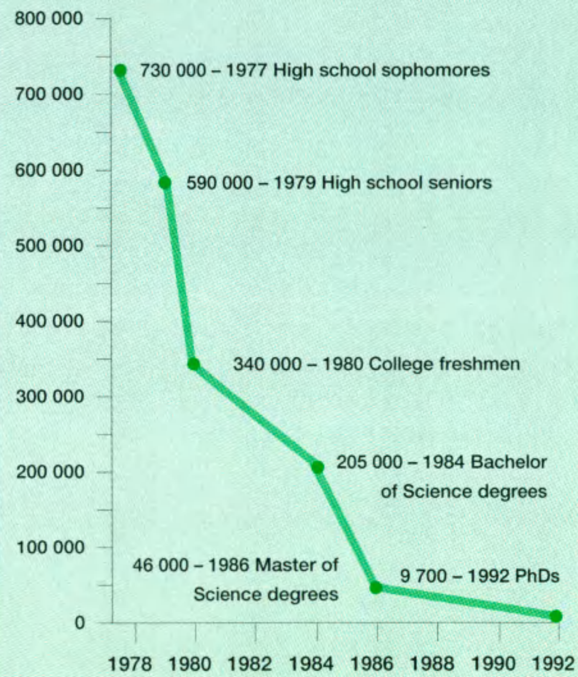
Why does the S&T environment fail to attract and retain highly qualified women? Studies in developing countries attribute much of this attrition to socio-cultural conditioning. Early marriages, adolescent pregnancies or economic practices including land inheritance customs that favour boys result in a lack of will and resources to support schooling for girls. Heavy household responsibilities and disproportionate domestic workloads consume girls' energy and limit their time available for schooling or recognized and remunerated work. Taken together, these factors work against girls' education at home or abroad.

The phenomenon of alienation of girls and women from S&T is by no means limited to developing countries. In the USA a recent study showed a series of watersheds where girls and women dropped out of science (see Figure 4). At each transition point, women left science at significantly higher rates than men.

Recent studies have explored the phenomenon of this 'leaky pipeline' in higher education and academia. One such study examining women in neuroscience in the USA

FIGURE 4
WATERSHED STEPS

Education pipeline for women in natural science/engineering in USA



Source: National Science Foundation.

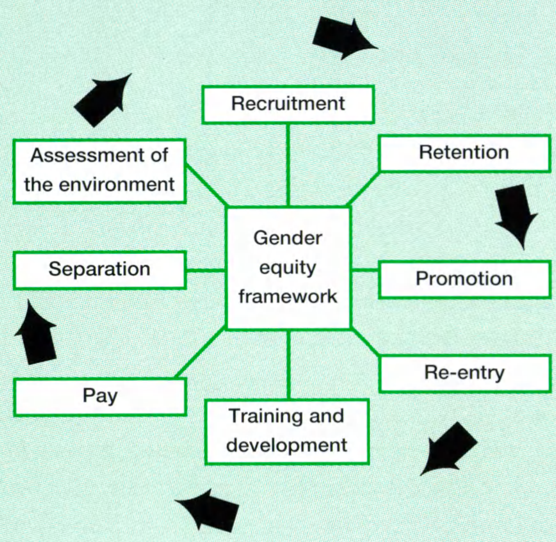
recorded that 45% of students entering graduate school were women. But while the pipeline supply may start out with notable numbers of women, even approaching equity, it leaks like a sieve. Only 38% of PhD graduates are women; one-third of these carry out post-doctoral studies and less than 18% enter the tenure track (Barinaga, 1993). In the USA, the National Science Foundation examined this phenomenon over time. It found that despite increasing efforts to attract women into science, the percentage of women among those receiving PhDs increased from 21% to just 28% between 1979 and 1989.

In other words, 'supply side strategies' need to be supplemented. Simply increasing enrolments is fruitless if the pipeline continues to leak all along the way. There is a clear need to focus on changing the policies and programmes of the institutional structures where science takes place.

The Australian report (Australia, 1994) adopted as one of the two principles underpinning its discussion of gender issues in science and technology the 'need for a paradigm shift away from asking what is wrong with girls and women to questioning what it is about the environment of science, engineering and technology that does not attract and retain the interest of girls and women'.

Such a conceptual shift from a deficiency model of girls and women to a deficiency model of science and science education is increasingly widely regarded as crucial if women are to receive equitable treatment in the sciences, and the sciences are to be able to take advantage of the potential that women scientists and technologists can offer.

FIGURE 5
POINTS OF POLICY INTERVENTION



CREATING ENABLING ENVIRONMENTS

A range of policy instruments and innovative strategies is available to redress historical imbalances and help dismantle discriminatory practices that have marginalized women from S&T communities.

Organizations can intervene at many points of entry to effect change and achieve gender equity. Figure 5 suggests a set of eight points where policy interventions could take place in an institution in order to lead to change. Each intervention requires the recognition that there are also differences among women defined by culture, class, race and ethnicity which add complexity to both the analysis and required action. Ultimately, affirmative action is needed in S&T decision-making and advisory bodies to address the pronounced absence of professional women from the decision-making arena.

Legislative tools for governments

Legislation is a powerful point of leverage. Some governments have enacted affirmative action legislation, such as that in Sweden, which states that when two candidates are equally matched, the applicant from the less represented sex should be favoured. Other governments have passed legislation, such as the USA Science and Technology Equal Opportunities Act. In 1988, England and Wales passed an Education Reform Act introducing science as a core course for children between the ages of 5 and 16. Pay equity legislation, policies to eliminate gender harassment, progressive parental leave policies and spousal support programmes are other tools to effect organizational and behavioural change and build enabling environments for both women and men (*Science*, 263, 1994; Canada, 1993; United Kingdom, 1993*b*).

Governments can require gender impact assessments to ensure the explicit articulation of 'whose needs' and 'whose interests' are being served by S&T priorities, programmes and products. Furthermore, governments have the power to enforce employment equity policies and can choose to tie the granting of funds to S&T institutions to successful implementation of gender equity policies and programmes. National implementation of such policies may explain, in part, why the public

TABLE 1
TOOLS AND STRATEGIES FOR POLICY INTERVENTIONS

Assessment of the environment
- Institutional self-evaluation questionnaires
- Climate evaluation and monitoring surveys
- Responsibility centres for equity evaluation, monitoring and reporting
- Foreign review panels

Recruitment
- Open advertising and competitions for positions
- Pro-active search techniques using women's professional networks, NGOs and the Internet to seek qualified female candidates
- Gender balanced interviewing teams and recruitment committees
- Gender neutral interviewing techniques and formats
- Targets for hiring qualified female professionals
- Designated fellowships for women; stipends to send girls to school
- Flexible overseas scholarships for women in science

Retention
- Senior management support; corporate policy; equity action plans
- Enforced corporate policies on gender and sexual harassment
- Corporate guidelines on language, illustrations and visual materials
- High visibility ombudspersons; women on grievance committees
- Appointment of women to powerful and high visibility committees
- Institutional support for professional women's networks and Internet policy discussion groups
- Recognition, support and reward of role model and mentoring programmes
- Supportive spousal employment programmes
- On-site childcare facilities and 'elder care' services

Promotion
- Flexible tenure and promotion criteria; changed reward system
- Succession planning and career counselling
- Equity targets with timelines and statistical tracking
- Regular public reporting of corporate performance
- Building of a pipeline of female candidates
- Gender neutral, bias-free performance appraisal system

Re-entry
- Flexi-time, flexi-location; job-sharing options
- Return to work directory on refresher courses, childcare options, mentors, role models and career counselling
- Career-break schemes and re-entry refresher courses
- Childcare allowances for applicants
- Progressive parental leave policies

Training and development
- Gender sensitivity training for teachers, students and staff
- Pedagogical training for teachers; curriculum revision; recognition of diverse ways of doing science and differing gender patterns in communication and learning styles
- Gender-neutral language, images and illustrations
- Training on gender, interviewing techniques, combating harassment etc.
- Executive-level internships for women

Pay
- Pay equity
- Equity in research funding

Separation
- Gender equity in separation packages
- Exit interviews with women

sector has achieved so much more success in attracting and retaining professional women scientists than the private sector. Governments are key to the systematic collection of disaggregated data on women in science and data on the impact of science on women and men. Moreover, governments can enact legislation to promote the recognition and protection of local knowledge systems and their gender dimension.

Strategies and tools in learning and employment environments

A set of tools and techniques are already available to assist organizations diagnose problem areas and introduce change. As instruments to effect organizational and personal behavioural change, these tools offer a wide range of options for action from the 'carrot' to the 'stick' approach. They include incentives, mentoring, scholarships and fellowships, public reporting on performance in gender equity and schedules for success.

A number of professional associations, including some in the fields of engineering, chemistry and human medicine, actively support professional women's networks to assist in identifying issues and designing solutions. These more progressive associations assume a much higher profile in terms of exposing biases, yet also serve as important leaders in working towards solutions. For example, the American Chemical Society in its annual survey (1991) recorded that women chemists earned on average only 88% of what their male counterparts earned, with controls for age, experience and qualification. These and other analyses have led to a range of gender equity initiatives in the profession, and the publication by the women's committee of a list identifying major chemistry departments in the country which still, in the 1990s, have no women on the tenure track. Recognizing and recording the issue is the first step towards finding a solution.

The science and technology professions can also learn from successful experiences in other sectors. Sport illustrates the interesting benefits from such cross-over sharing of successes. National and international organizations advancing girls and women in sport have developed a wide range of tools, policies and guidelines relating to harassment, gender equity, access to facilities, mentoring and role modeling at national and international levels, to facilitate the full participation of women in sport. Furthermore, as athlete and scientist Leigh Handy Royden of MIT personally experienced, there can also be a reinforcing relationship between athletics and the self-empowerment of women professionally: 'One of the things that helped me as a woman in science was my athletic career. It teaches you to compete physically and also psychologically in the face of outside pressures... while men get this training, very few women do' (*Science*, 1992, 255: 1388).

Table 1 lists a range of tools and strategies available to organizations and school systems to help evaluate gender equity issues and initiate solutions. These examples have been drawn from both the public and private sectors and illustrate actions possible at various points of entry into institutions in order to effect personal and organizational change.

Tools in the decision-making arena

Ultimately, in order to effect change and contribute fully to science and technology, women must be present in critical number and at a critical level in decision making in S&T institutions, departments, advisory boards, development agencies and educational institutions. At present the participation of professional women is negligible in S&T decision-making bodies and high-level advisory boards (see Table 2).

Purposeful attention is needed to seek out candidates to serve in this capacity. Such recommendations abound in the literature and in national task force reports. To facilitate achieving this goal, it is important to create databases of qualified women scientists and technologists as potential candidates, and fully to utilize those databanks currently in existence including

TABLE 2
SELECTED NATIONAL ADVISORY BOARD MEMBERSHIP

Organization	Total membership	Female membership
AUSTRALIA		
Prime Minister's Science Council, Office of the Chief Scientist, Department of the Prime Minister and Cabinet	22	4
CANADA		
National Advisory Board on Science and Technology	20	5
EGYPT		
The Supreme Ministerial Committee for Science, Research and Technology	13	1
EUROPEAN COMMUNITY		
Committee for the European Development of Science and Technology	30	1
FRANCE		
Higher Council for Research and Technology	40	2
JAPAN		
Council for Science and Technology	11	2
NETHERLANDS		
Advisory Board on Science and Technology	12	1
UNITED KINGDOM		
Council for Science and Technology	12	1
UNITED STATES OF AMERICA		
President's Committee of Advisors on Science and Technology	18	6

worldwide networks of professional women's associations and non-governmental organizations working in policies and programmes on gender, science and technology. Internationally, UNIFEM has an electronic database of some 650 NGOs involved in issues of gender, science and technology, many of which took an active role in promoting S&T at the 1995 Fourth World Conference on Women (see p. 340).

Conclusion

Answering the question 'Science *by* whom?' often serves to render visible a set of inequities and to reveal a range of biases which have militated against the full participation of women in science and technology and marginalized their pool of talent. Acknowledging and addressing these inequities and biases provokes profound reconsideration of our attitudes and approaches and provides a natural bridge to the broader question 'Science *for* whom?'

Science for whom?

SANDRA HARDING AND ELIZABETH McGREGOR

For whom should science produce knowledge of nature and social relations? Asking this question directs attention to patterns of systematic ignorance generated for everyone when the interests of social groups such as women are excluded from the decision-making process determining which problems need scientific attention and just how these issues should be formulated.

Most observers around the world doubt that transferring 'ready made' modern S&T to developing societies has been, or could be, a solution to globally uneven development or to global inequity. This S&T was designed for different natural and social circumstances than those now prevailing in most of the developing world, and for different natural and social goals than those of greatest importance to developing societies. Indeed, considering the environmental and human destructive power that modern S&T has made available in the last 50 years, many people now fear that at least those parts of modern S&T are no longer suitable for developed societies either.

There is no doubt that many of the issues raised in the preceding sections are crucial for increasing the well-being of the most economically, socially and politically vulnerable women and men around the world. However, focusing exclusively or primarily on how to give girls and women in developing and developed societies more access to careers in modern S&T cannot avoid appearing to many to be a project of dubious social value to the majority of the world's peoples as long as the larger issue of 'Science for whom?' remains unaddressed.

Within science and technology communities, women scientists have sometimes been able to find ways to use their experiences and interests 'outside the lab' or apart from field work to illuminate previously ignored aspects of nature – most obviously, women's bodies and their interactions with environments, and other areas where nature and social relations both play a role in what has often been thought of only as 'nature'. Questioning about whether at least some women might tend to favour different styles of doing scientific research has led to appreciation of the possibilities of enriching our knowledge through greater inclusiveness of human talents and abilities. Modern scientific communities have always recognized the importance of including people who tend to think in diverse ways in order to look at nature from as many perspectives as possible. Gender differences, too, can increase such diversity (see below).

Some of the very characteristics that make the modern sciences so immensely effective for producing solutions to some kinds of problems also limit their usefulness for others. Consider, for example, the case of environmental sciences. Here observers have pointed out that they all too often exclude from consideration exactly the kinds of social analyses that are crucial for understanding patterns of local environmental maintenance and degradation. Focusing on scientific approaches to environmental problems also tends to tilt analysis away from lived experiences and local conditions in an environment to outside expertise that devalues local knowledge and to universalizing explanations that are of limited usefulness under local conditions. Finally, scientific approaches can give scientists and the public alike the impression of a greater certainty about how nature works and about proposed solutions to problems than may turn out to be warranted (Seager, 1993). Recognition of these kinds of limitations of scientific solutions to environmental problems leads to a renewed appreciation of the importance of local knowledge systems and, especially, of women's under-appreciated roles in these knowledge systems (see opposite).

Local knowledge systems were discussed in more detail earlier. These knowledge systems are often contrasted with the universal validity of modern science's claims, and this contrast captures important features of both systems. Yet it also obscures important characteristics of each and of relations between them. Modern science's knowledge is also shaped by 'local'

Women, science and the environment

BONNIE KETTEL[1]

When you look at the landscape, what do you see? Are there aspects of your natural environment that you would like to maintain or improve? Are there others you find unnecessary or detrimental? To what extent are your perceptions and preferences regarding the use and management of the natural environment similar to those of other people in your household and community?

Research carried out by the WEDNET team in Africa suggests that environmental perceptions are often gendered, and that the elements of the natural environment known and valued by women and men may be very different, regardless of the cultural or regional setting (Kettel (1995) *Gender and Environment: Lessons from WEDNET*, Westview). The gendered nature of people's perceptions about the environment is not limited to knowledge of different plant and animal species. Women and men may have a different focus and level of awareness with regard to the ecosystemic associations that link various aspects of nature. In a recent ECOGEN case study, Rocheleau reported that women in Kathama, Kenya, played a central role in helping the community to survive a drought that sent every resident into the fields and hedgerows to scour the natural environment for food (Clark University, 1992).

Over the last few decades, a great deal of scientific research and technological innovation has been devoted to better meeting a key set of environmental perceptions and preferences, in order to improve living standards and raise incomes. Science and technology have allowed us constantly to test nature's limits in pursuit of ever greater efficiency, productivity and profit. However, two profound dilemmas have arisen.

First, we know that many of these scientific and technological interventions, no matter how well meant, have been limited in their success and, all too often, ultimately detrimental to the sustainability of the natural environment (see, for example, Timberlake, L. (1985) *Africa in Crisis: The Causes and Cures of Environmental Bankruptcy*, Earthscan). We also know that in spite of all our scientific and technological effort, women's poverty – especially compared to men in their own households and communities – has continued to rise.

Furthermore, women have been disproportionately exposed to the consequences of environmental degradation, in both rural and urban areas, particularly through their activities in the collection of fuelwood and water, the production of food crops, and through their work in the maintenance of homes and neighbourhoods (Jacobson (1992) Worldwatch Paper No. 110).

The invisibility of women's 'landscape' in scientific and technological research and application has had profoundly negative impacts on women's income and well-being. In addition, the failure of development planners, scientists and technological innovators alike to recognize that women may see and understand the natural environment differently from men, and have very different interests and goals in the use and management of their local environment, has also had a profoundly negative impact on the sustainable management of local ecosystems. We have viewed nature through only one eye, and with one side of our collective human brain. But careful use and sustainable management of local – and planetary – ecosystems surely requires full human sight and insight.

Perhaps women's views and goals, which generally include the well-being of their children, female and male, should even be accorded comparatively greater weight than men's in our global quest for a sustainable human future (Steady, F. (1993) *Women and Children First*, Schenkman). But one conclusion is clear: a great deal of new scientific and technological research and application, in support of women's environmental perceptions, knowledge and goals, is waiting to be done.

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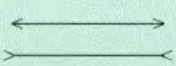
interests and knowledge traditions (for example the career, disciplinary and universalizing interests of 'experts'). Moreover, modern science has incorporated much from earlier local knowledge systems of Europe, Asia, the Americas and other parts of the world – Arabic numerals, Indian mathematical notions or agricultural principles of Andean potato-growers. Furthermore, as European cultures expanded, modern science was able to reflect on observations of nature made in many parts of the world by peoples drawing on many different cultural traditions of knowledge seeking. Knowledge developed in local contexts has often become universally valid through such historical processes (Goonatilake, 1984). Indeed, modern science can only be developed

Women, science and the world view

SHIRLEY MALCOLM[1]

In a psychology class some years ago, I learned about a group of people who were not fooled by an optical illusion which fooled almost all the rest of us. When asked to judge two lines of identical length, but with arrows at the ends pointing in opposite directions, we characteristically 'see' line (b) to be longer than line (a), because of the pattern of which it is a part.

(a)
(b)



In a classic work by Segall, Campbell and Herskovits, *The Influence of Culture on Visual Perception* (1966), groups who lived with few lines were found to be less susceptible to the illusion. A part of their culture, the way they were raised, the world in which they lived, left them free of the perceptual bias that had caught me. I learned that in a rounded world, having homes without corners, using few straight lines, their perception of the lines and the pattern was different from mine.

So also, when little boys and little girls are raised differently, as they are in the USA, they acquire different perspectives and perceptions. The notion of unisex child rearing practices is a fairly recent one and not regularly adhered to, in any case, by parents, such as I, who find it difficult to escape tradition. I want my daughters to have the doll's house that I had, as well as the train that I didn't have. As a result of my own rearing, I cannot escape the fact that I acquired a different world view.

Sons and daughters continue to be raised differently. The biological differences between them are real, as are the interactions of biology and culture. For humans, culture overrides much of biology. I believe that while the gender effect does not relate to the ability to solve problems, it probably does affect the processes by which they are solved. Instead of seeing a 'deficit' model in this diversity, however, I view a 'difference' model and see strength in those differences.

Many of us work long and hard to get more women into science and engineering careers. There are a lot of reasons why we do this, reasons related to economics, equality of access, relative employment stability and utilization of talent, as well as personal satisfaction and intellectual challenge for the women involved. We also do this because science and technology are not as good as they could be when 'other' perspectives are missing. If women and minorities are excluded, other viewpoints of the world are being lost.

Science itself uses the argument of diverse perspectives to support the idea of mixed age groupings on science faculties, international exchanges of scientists or multi-national research institutes. A study by Albert Teich, *Scientists and Public Affairs* (1974, MIT Press), of European research laboratories such as CERN, indicated that the scientists at the laboratories felt that they gained much from having access to and interaction with colleagues who had a different cultural history and tradition, and that these differences affected the way each perceived the world. Interestingly, it affected the way they arrived at conclusions – not necessarily changing the final answers, but definitely affecting the processes of arriving at them. And the and then used in local settings – even though a 'local setting' can extend from Cape Canaveral to the Moon or Jupiter.

Science's creators, users and observers have come to understand during the last three decades of development that the scientific and technological changes that can most improve social conditions are those where attaining an appropriate interplay between local knowledge and abstract principles has been of primary concern. Insofar as women have different biologies, different socially assigned activities and different ways of organizing the production of knowledge, they will tend to have different interests, hopes and interactions with natural and social environments and thus be able to generate additional knowledge. Because women around the globe deliver provision and care to the three generations that depend upon their daily services, as well as to the larger communities in which they participate, science that is for women too – for women as well as men – can greatly enlarge every community's resources through the multiplier effect.

processes themselves suggest new questions, new connections and new relationships, all matters of great importance to activities on the frontiers of knowledge.

Having diversity among the doers of science may mean looking at a troop of baboons and defining it to be held together by male aggressive behaviour – or by female friendships. Having such alternatives presented may lead to a truer assessment of the social organization. Diversity of perspectives may make the difference in designing a study of hypertension which involves only males or one which includes females for comparison, as the 'success model'. Or it may only mean developing an algorithm through one thought process as opposed to another. But when there is mass exclusion of a group of people, with a different set of perspectives and world views – whether intentional or coincidental – the profession is the poorer.

In view of the pivotal role of science and technology in our lives, I believe we must be especially careful that these fields are not an exclusive club. All people must be prized for the different perspectives they can potentially bring to the scientific process. The talents of all interested and able people must be carefully nurtured, lest an indifferent society or a negative one turn them away because of their differences from the majority of present participants. I'm glad I learned about the people who were not fooled by the optical illusion. Maybe a more heterogenous world view in science will keep us honest about a lot of other things as well.

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ARE THERE WOMEN'S STYLES OF DOING SCIENCE?

This old question has gained new life in recent years. Some patterns of difference consistently emerge in the small number of studies that exist and in anecdotal evidence. A report in *Science* summarizes these studies (Barinaga, 1993). For one thing, many observers think that women lab directors tend to reduce competitive relations between their assistants and students, while men tend to encourage them. Indeed, this difference in attitude towards competition appears to extend to the choice of research topics. According to one study, men often seem to prefer 'hot topics', where research groups are competing, while women more often prefer a 'niche approach', 'where they can develop mastery and deal with a relatively limited number of colleagues who are interested in the same field'. One outcome of this difference in approach appears to be that 'while women publish less, their papers were nevertheless cited at a higher rate'. According to the authors of this study, one possibility here is that 'women tend to take more seriously the internal requirement to turn out very thorough articles rather than just turning out a lot of articles'.

A related difference appears in women's comfort with collaboration rather than only with individually conducted research. (It is not clear that this difference would hold up were gender preferences surveyed cross-culturally; in some societies it is men who are more used to collaboration (Traweek, 1988).) Moreover, women often seem to prefer to collaborate with other women. Observers suggest that this choice may originate in the different styles of conflict resolution with which men and women are most comfortable. In one study, women were 'more likely to say they listen to all perspectives and try to come up with a compromise, while men were more likely to say they try to persuade others to adopt their point of view'. When these two approaches are both working in a research group, women will tend to feel 'overlooked, unheard, and even squeezed out'.

Do gender styles create different sciences, or just different ways of going about producing the 'same' science? In many scientific projects and, indeed, vast areas of research, the same results will be produced, for where the problems addressed, favoured hypotheses, concepts, research designs, interpretations of data and evaluations of evidence are shared by women and men researchers, it would be hard to see how the kinds of gender differences discussed here could make a difference in the results of research. However, in other kinds of research projects, and especially in those which are more concerned with applied science and where natural and social regularities co-shape a problem, it is harder to separate matters of style from those of interest.

A great deal of scientific research is of this sort. In these cases, gender differences mark just one of many culturally shaped differences in the kinds of problems that culturally different groups of scientists will find interesting and valuable and, consequently, in the ways they will organize the process of research, as many studies in the last 30 years of the history of science have demonstrated. Primatology is one research area often cited as an example where three women – Goodall, Fossey and Gladikas – shaped their field through a distinctively different style of working with primates. Other examples can be identified in such areas as environmental, medical and health sciences. Of course there is nothing in these literatures to suggest that biological differences are the cause of these different styles. Nor is there any suggestion that men could not learn to use these styles; indeed, in many cases there are already men who do.

Gender differences in scientific styles may well turn out to be one of the most important newly identified resources for the growth of scientific knowledge. Good science should value diverse forms of arriving at less partial and distorted results of research. The goal should be for everyone to expand their human capacities and interests in nature rather than remaining confined to understanding only what can be seen through rigid gender blinkers.

The potential to be realized

ELIZABETH McGREGOR AND SANDRA HARDING

Why should governments and the global scientific community address the gender dimension of scientific and technological development? Most obviously, considerations of equity and human rights motivate policy leaders. This fundamental commitment is articulated in the United Nations Charter of Rights to which Member States subscribed in 1945.

Fifty years later these tenets remain equally compelling. In 1995, the Gender Working Group of the United Nations Commission on Science and Technology for Development issued its final report, *Science and Technology for Sustainable Human Development: The Gender Dimension* (GWG-UNCSTD, 1995*b*), in which it called upon governments to endorse a Declaration of Intent setting out six goals of gender equity in science and technology as follows:

- To ensure basic education for all, with particular emphasis on scientific and technological literacy, so that all women and men can effectively use science and technology to meet basic needs.
- To ensure that men and women have equal opportunity to acquire advanced training in science and technology and to pursue careers as technologists, scientists and engineers.
- To achieve gender equity within science and technology institutions, including policy and decision-making bodies.
- To ensure that the needs and aspirations of women and men are equally taken into account in the setting of research priorities and in the design, transfer and application of new technologies.
- To ensure all men and women have equal access to the information and knowledge, particularly scientific and technological knowledge, that they need to improve their standard of living and quality of life.
- To recognize local knowledge systems, where they exist, and their gender-specific nature as a source of knowledge complementary to modern science and technology and also valuable for sustainable human development.

Speaking at the ORSTOM/UNESCO[1] conference, 20th Century Science: Beyond the Metropolis, in September, 1994, Professor Geoffrey Oldham, Chairperson of the GWG of the CSTD, remarked in his plenary address:

> 'There is a need for the international scientific community to take a stand on what it considers fair, just and ethical in a number of science and technology related issues. Pugwash did play that role to a limited extent in the 1970s but other NGOs may be in a better place to do so in the 1990s. Issues which could be addressed include... equity of opportunities for women in scientific and technological careers' (Oldham, 1994).

Consideration of equity and human rights in S&T implies equal access to scientific literacy in order that both women and men may make informed decisions about the many scientific and technological matters that impact upon their daily lives. It also implies equal opportunities and rights to contribute to scientific and technological advances, equal access to the social and economic benefits that accompany scientific careers, equal share in designing and evaluating S&T policies and equal benefits as 'science consumers' from S&T investments and advances.

These last two equity issues are specially important, since the design and evaluation of S&T projects have not systematically included an initial analysis and subsequent evaluation of the differential impact of S&T policies and programmes on the lives of men and women. This omission has contributed to situations in which S&T development policies, projects and technologies have been inappropriately formulated and designed with respect to women's needs and interests and historically have benefited men more

1. ORSTOM: Institut français de recherche pour le développement en coopération.

than women (GWG-UNCSTD, 1995*b*).

Increasingly, governments are also viewing gender equity in the context of national strategic advantage in the global marketplace. There is pressing interest in many countries to maximize everyone's creativity and ingenuity in science and technology in order to increase economic growth to achieve quality of life for all. Marginalization of half of a nation's talent just does not make good sense. In 1993 the UK Committee on Women in Science, Engineering and Technology, in its report to the Office of Science and Technology entitled *The Rising Tide* (United Kingdom, 1993*b*), acknowledged that women were the country's most under-utilized resource. In Canada, the 1993 report of the Prime Minister's National Advisory Board on Science and Technology (NABST) entitled *Winning with Women in Trades, Technology, Science and Engineering* called for gender equity in science and technology in the context of positioning the country for global competitive readiness:

'In a climate of significant national and global economic restructuring... it is critically important that the nation's work-force attain and maintain a state of technological and scientific readiness that will enable it to thrive in the global economy. To ensure this readiness, it is essential that the potential of all sectors of the population is fully utilized. The potential contribution of women has been and still is undervalued and under-utilized. Recognizing this fact, and in particular that barriers still exist to women's full participation in the scientific and technical fields, strategies to remove these barriers are required at all stages of women's educational and employment development' (Canada, 1993: 3).

In developing nations, where science and technology are important transformative tools for achieving sustainable development, tapping into women's talent can be in the 'strategic interest of countries' (Approtech, 1993). Remarking upon the gender gap in the education of girls and boys in developing nations, the World Bank publication *Educating Girls and Women: Investing in Development* noted the high development cost – in lost opportunities to raise productivity and income, as well as quality of life – where governments and society fail to address issues of inequity in access to education.

The research community is called upon to act in its own self-interest and make a conscious effort to 'integrate itself into the larger community' by more closely reflecting the demographic composition of the population (Neal Lane, Director of the NSF, cited in Etzkowitz, 1994). Isolation and elitism not only erode support for science communities but also deprive them of contributions from the full range of end-users, and reduce important interactions that would help to ensure the relevance of their policies and projects to all members of society.

In addition, science communities are examining the benefits of recruiting and retaining women scientists and engineers in terms of the value of increasing different perspectives, priorities and operating styles while creating a workforce with greater diversity of skills. Those science and technology communities that have understood the historic importance of such inclusiveness have become more valuable agents of social development. It may not be so much an issue of whether women produce a 'different science', as a principle of producing science relevant to societal needs and reflecting all interests in society.

Hence, not only considerations of equity and human rights but also diverse kinds of self-interest give governments, development agencies and science and technology communities good reasons to ensure that women have equal access both to scientific and technical education and careers, and to full participation in every level of the science and technology decision-making structure. Scientific communities and all members of society will benefit from the full participation of women in the process of making decisions as to which scientific and technological projects are prioritized, how they are conceptualized and implemented, how the evidence is sorted and how the results are evaluated and disseminated.

Global perspectives

Challenges in interpreting data

ANN HIBNER KOBLITZ

Research on the subject of women in science and technology is still at a very preliminary stage. Nevertheless, it is clear that there are good reasons to avoid sweeping generalizations and simplistic conclusions. For example:

- While there is a considerable amount of commonality of women's experiences in the sciences, perhaps especially in neighbouring countries with similar cultures, economies and histories, there are also many variations. A scientific or technical field that might be considered 'unwomanly' in one country in a given period may enjoy the participation of many women in a different historical period or in another country. An example is engineering, which in many countries is considered the exclusive domain of men, especially in usually prestigious sub-fields such as electrical or mechanical engineering. There are exceptions to this, however. In the former Soviet Union all sub-specialities of engineering had high percentages of women, and at the Universidad Nacional de Ingenieria of Nicaragua, women made up 70% of engineering students in 1990 (personal observation).
- The position of women in science, technology and medicine – and in society as a whole – does not improve constantly and linearly. For example, there have been instances where the gains of women in scientific professions in the 19th century were eroded in the 20th century. Many medical schools for women (and African Americans) that had flourished in the USA in the 19th century were closed down by the American Medical Association at the beginning of the 20th century. Another example is the treatment of North American (and European) women chemists and engineers who had worked at highly technical jobs throughout the First World War, and were then forced to give up their positions to men after the war ended (Rossiter, 1982). And 'the percentage of women who are full professors in the Federal Republic of Germany is less than the percentage of women students in 1910' (Osborn, 1994).

One can see erosion in the position of women scientists in other areas as well. The percentages of women in USA computer science programmes, for example, are going down, and the current situation for women scientists in the former socialist states of Eastern Europe is nothing short of tragic (*Science*, 263, 1994: 1477; Koblitz, 1993). Moreover, one can sometimes see the percentages of women in science in some speciality, work area or country increase, but for essentially negative reasons. For example, in the latest round of structural adjustment programmes and economic retrenchments, national universities in Latin America are being particularly hard hit. Women are finding themselves to be an increasing percentage of national university faculties in the sciences, but only because men are deserting the universities for more lucrative positions in the private sector.

The position of women in science, technology and medicine is not necessarily positively correlated with the generally accepted indices of economic development. There are many developed countries, including a large number in northern and western Europe and North America, that have rather pathetic rates of participation of women in science compared to those of many developing countries. The Scandinavian countries, (Western) Germany, the Netherlands and the UK have particularly low percentages of women scientists in most fields. Mediterranean countries such as Italy and Turkey, on the other hand, seem to do much better.

Women can often be effectively segregated or marginalized within scientific and technical fields, even when their aggregate percentages look reasonably good. It is quite common, for example, for university teaching to be a rather feminized sector, especially at the low ranks of instructor and lecturer.

Also, one occasionally finds that women have consciously or unconsciously segregated themselves into certain fields, possibly in an effort to carve out a place for themselves in the natural sciences. For example, women in the United States in the late 19th and early 20th centuries attempted to make room for themselves by creating the disciplines of home economics and nutrition. Women scientists soon found themselves largely restricted to those fields, and had a difficult time securing employment outside them (Rossiter, 1982).

Women's contributions in many areas of science, technology and medicine have been far greater than most people suppose. There is a need for further research and there is an even greater need for dissemination of information on the subject. Truly comparable cross-cultural statistics are also lacking. To take just one example: a truly cultural survey of when and under what circumstances women entered the universities – and which fields of study welcomed them first – could prove extremely enlightening. In some countries of continental Europe, for instance, the first women to receive doctorates and teach at the university level in any academic disciplines were in physiology, anatomy, mathematics, physics and chemistry; professors in the so-called humanities were more reluctant to admit women to their ranks.

Women's experiences in the sciences, technology and medicine across disciplines, cultures and historical periods, have been diverse and often show contradictory tendencies. We should therefore be extremely hesitant to make sweeping generalizations about the female nature, women's roles under patriarchy, etc. The interactions of gender, culture and science are complex; it is unwise to draw simplistic conclusions that stereotype women's participation and status in the sciences.

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NOTE

This report was written by Professor Koblitz as consultant to the Statistical Division of the United Nations, as part of the research programme for the preparation of the United Nations publication *The World's Women 1995: Trends and Statistics*. It is used here with the permission of the United Nations.

Women in science: the case of Africa

LYDIA P. MAKHUBU

In a very cogent observation, Abdus Salam, founding President of the Third World Academy of Sciences, stated that, 'In the final analysis, creation, mastery and utilization of modern science and technology is basically what distinguishes the South from the North' (Salam, 1990).

This observation accords science and technology a special role in development, designating them as key determinants of socio-economic progress. It may be added that mastery and utilization of S&T in the North have gone beyond construction of sophisticated industries and other physical infrastructure to a fusion of science and culture to produce a self-sustaining and continuous social metamorphosis which touches all aspects of human life. Science and technology have become a way of life enabling societies to move from 'ground-level subsistence' (Odhiambo, 1994) to highly productive entities propelled by an unprecendented and rapid process of scientific knowledge generation.

TABLE 1
NUMBERS OF SCIENTISTS AND ENGINEERS IN SELECTED REGIONS

Actual numbers of S&T specialists	
Newly industrialized countries in Asia	92 300
Africa	73 100
Israel	20 100
Specialists per 10 000 population	
Africa	1.1
Latin America	3.6
Newly industrialized countries in Asia	10.0
Europe	22.0
North America	33.6
Israel	44.0

Source: UNESCO, *Statistical Yearbook*, 1993.

The greatest challenge, therefore, facing advocates of science-led development in Africa today, is devising mechanisms to fuse science and African cultures in such a way that science becomes a driving force for the improvement of the overall quality of life of all people.

A closer look at the situation in industrialized countries reveals that the creation of an environment to foster the growth of science is critical in S&T advancement. The essential prerequisites in this process include the adoption of policies to promote scientific research and substantial investment in the development of human resources and infrastructure in science at all levels. On expenditure, it is noted that African countries spend nearly one-tenth of the percentage of gross domestic product that industrialized countries devote to S&T, a factor which has rendered Africa extremely weak in every aspect of scientific development. For example Africa has not been able to produce the critical mass of specialists to provide effective and innovative scientific leadership to spearhead successful scientific research and other vital aspects of science-led development. This is shown by the gross discrepancies in scientific human capital between Africa and some other regions of the world, indicated in Table 1.

The lack of adequate indigenous human capital to participate in the global scientific revolution and to contribute to the creation of new knowledge through proper exploitation of the continent's vast natural resources, is a major and serious drawback to African development. It is critical that priority be given to the generation of human resources with sufficient enterprise to direct the scientific endeavour towards a total science-led socio-cultural transformation of Africa. Such transformation should liberate the continent from hunger, malnutrition and disease and facilitate measures for the arrest of escalating environmental degradation. In Africa, where 70-80% of the population resides in rural areas, successful application of S&T to development will be indicated by the extent of upliftment of the quality of life of the majority of the population (Makhubu, 1993). This upliftment however cannot be expected to occur without the participation of the population, who must appreciate the benefits of science, thus paving the way for its cultural integration.

It must be said that there has been no lack of effort to address these deficiencies in scientific progress in Africa. However, the past two decades have seen a multitude of economic problems and political turmoil that have diverted attention from such key issues as building continental capacities in areas such as science. It is in this context that the promotion of women in science is advocated, not merely as a matter of equity, but as an important means of strengthening the continent's scientific capacities to tackle the multi-dimensional problems that have become endemic in many countries (*ibid.*). Women, who constitute nearly 50% of Africa's population, and are traditional educators and transmitters of traditional values and norms, are a rich and untapped resource which the African continent cannot afford to ignore, especially at this time of social transition.

At the present time, women are grossly under-represented in science at all levels of the educational system and in particular at university level. The reasons for this are many and complex and include socio-cultural attitudes towards the education of women, teachers' attitudes towards girls enrolled in scientific disciplines and the attitude of girls and women themselves towards the study of science,

TABLE 2

ENROLMENT[1] FOR SELECTED FACULTIES IN SELECTED UNIVERSITIES, SHOWING TOTAL NUMBER OF STUDENTS AND THE PERCENTAGE REPRESENTATION OF FEMALES

		Humanities		Law		Social sciences		Natural sciences		Mathematics/ computer science		Medical courses		Engineering		Agriculture	
Country	Date	Total	%F	Total	%F	Total	%F	Total	%F	Total	%F	Total	%F	Total	%F	Total	%F
Angola	1990	–	–	860	–	–	–	609	40	na	na	834	42	779	21	379	32
Burkina Faso	1990	936	39	493	27	1 203	23	563	12	433	5	414	18	–	–	110	8
Burundi	1991	628	30	292	31	431	28	421	29	77	34	283	26	330	9	440	18
Ethiopia	1991	704	28	222	10	2 591	22	1 700	6	468	9	929	6	2 070	5	1 387	9
Ghana	1990	2 339	31	39	50	804	27	955	15	206	11	824	23	635	3	479	11
Kenya	1989	5 448	28	632	32	na	na	1 966	15	na	na	1 106	22	854	4	1 808	23
Lesotho	1991	459	65	132	43	69	58	312	36	na	na	–	–	–	–	19	84
Niger	1989	709	14	851	3	636	21	280	6	na	na	432	26	98	4	164	6
Swaziland	1991	287	63	205	40	233	51	341	33	na	na	–	–	–	–	90	28
Uganda	1990	636	33	169	34	1 166	26	880	15	155	10	561	22	207	8	598	18
Zambia	1989	1 161	28	145	23	na	na	757	14	na	na	349	28	551	1	228	7
Zimbabwe	1991	1 321	38	345	32	1 885	29	1 301	19	na	na	866	27	725	30	357	16
Kuwait	1991	2 257	66	602	50	1 580	74	1 593	65	1 636	72	791	63	1 342	39	–	–
Brazil	1991	140 566	74	159 390	44	161 214	57	41 158	49	70 898	38	137 602	64	150 015	17	38 700	30
Mexico	1990	15 003	57	121 621	40	80 792	59	39 541	54	51 751	41	94 622	54	279 989	16	24 620	21
Italy	1991	207 046	80	244 446	53	375 341	47	97 945	51	49 910	42	110 644	50	165 480	11	32 097	34
Sweden	1991	2 763	64	5 174	54	5 606	74	3 425	53	6 504	19	8 994	62	20 124	21	1 205	45

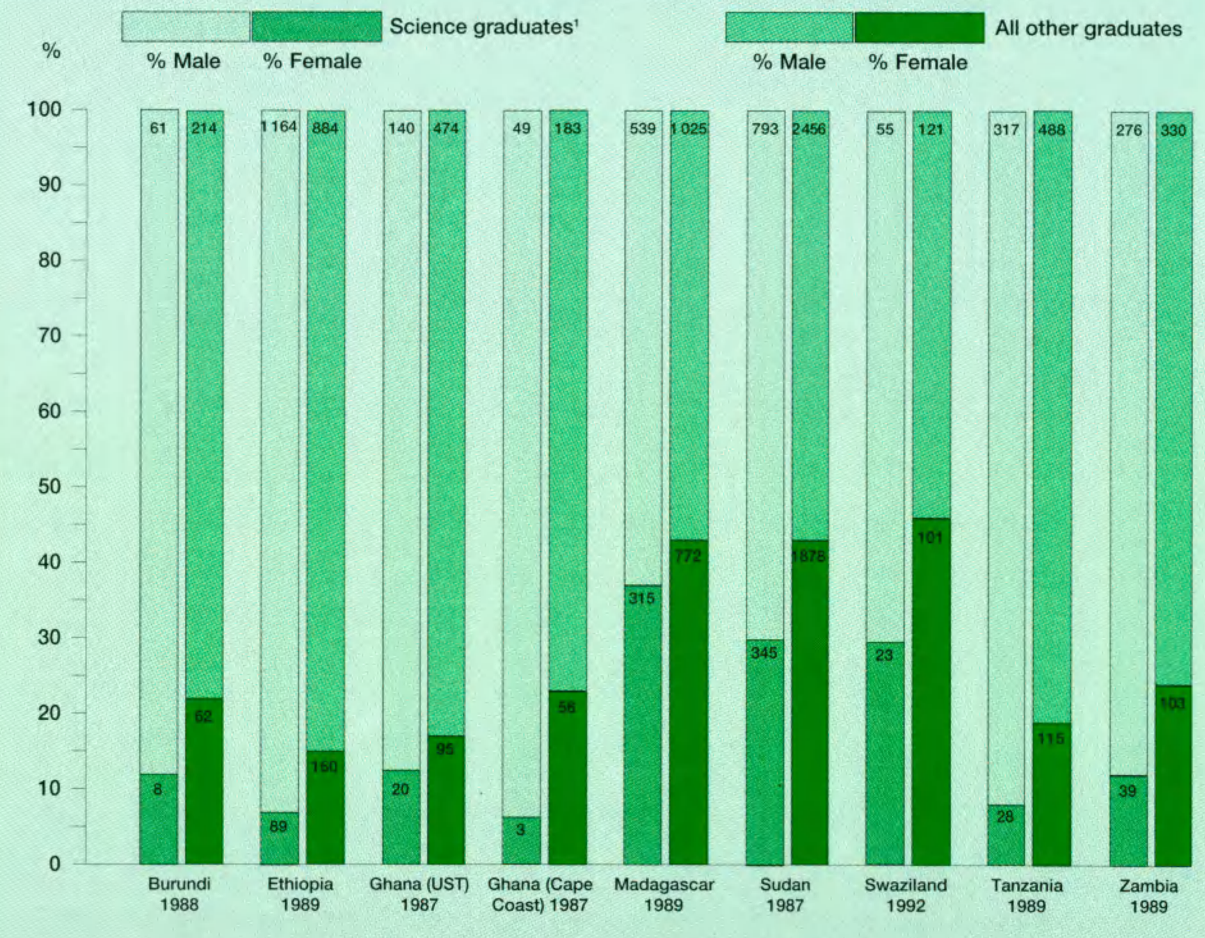
1. Figures given represent enrolment in courses leading to a first degree.
na = not available because subsumed under another faculty.

Source: compiled from data in the UNESCO *Statistical Yearbook*, 1993.

which is generally regarded as a male domain. All these factors have the effect of severely limiting the entry of women into scientific careers and consequently their upward mobility into scientific leadership and decision making. These points are well illustrated by the numbers of women enrolled and graduating from faculties of science and science-based disciplines and the numbers of women staff in science faculties, in selected African universities (see Table 2 and Figures 1 and 2).

While reflecting upon the positive effects of science and technology on human life, it is essential to consider how these can be brought to bear on the most pressing problems of Africa. These urgent problems, which touch upon human survival and have at times threatened whole communities, include inadequate food production, health and educational

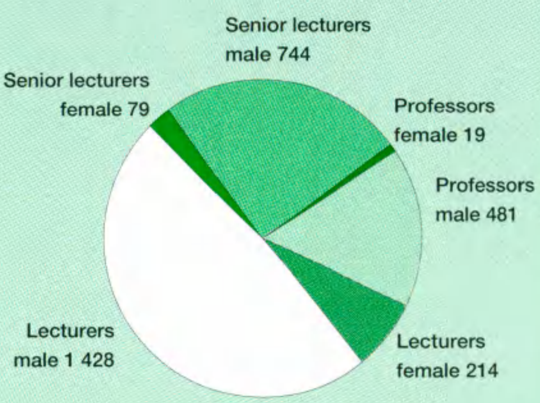
FIGURE 1
GRADUATE PRODUCTION, FOR SELECTED AFRICAN UNIVERSITIES, BY GENDER AND FIELD OF STUDY



1. Science comprises the natural sciences, medicine, agriculture, mathematics and engineering.
Note: Figures on bars are actual numbers of male and female graduates.

Source: compiled from various publications and records.

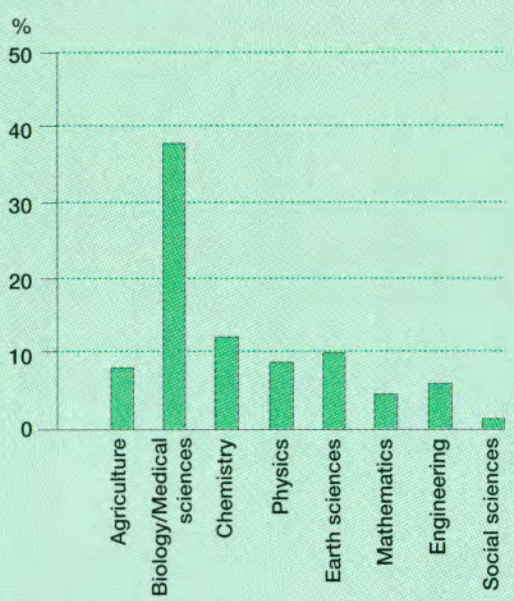
FIGURE 2
SCIENCE STAFF BY RANK AND GENDER IN 10 AFRICAN UNIVERSITIES[1], 1992



1. Botswana, Ghana, Ibadan, Lesotho, Malawi, Nairobi, Swaziland, Tanzania, Zambia, Zimbabwe.

Source: compiled from *Commonwealth Universities Yearbook*, 1993.

FIGURE 3
THIRD WORLD ORGANIZATION FOR WOMEN IN SCIENCE: MEMBERSHIP BY DISCIPLINE, 1995



Percentage distribution of 1 077 members

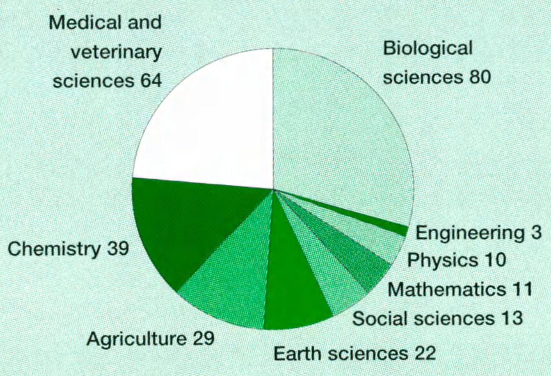
Source: TWOWS Report.

services, and degradation of the environment. All these can be ameliorated by the appropriate application of science and technology. It is in this regard that the contribution of African women scientists is considered critical and significant. Important as grassroots programmes are, it is even more important to promote the representation of women in educational and scientific leadership roles, to provide role models and strong advocacy for the advancement of women.

African women scientists, like most female scientists around the world, have shown a marked tendency to study the biological, chemical, nutritional and other life sciences. This is illustrated by the disciplinary membership distribution of the Third World Organization for Women in Science (TWOWS) and the TWOWS African membership (Figures 3 and 4). These figures clearly indicate female strength in biology, chemistry, medical science etc., all areas of close relevance to Africa's pressing problems. African countries should capitalize and build on this strength by vigorously promoting women to pursue careers in science as one means of finding ways to use science to solve their crippling problems. It has also been argued that, by their closeness to family and children, women have a unique approach to science and its applications – one which emphasizes the human dimension – and hence their tendency to study the life sciences. This tendency is a tremendous advantage to Africa in particular, and should be developed.

The contribution of African women to the scientific development of the continent can also be considered from the point of view of their traditional roles. The traditional roles of women have involved them in food production and in other areas which are closely related to the scientific disciplines mentioned. The translation of these traditional roles into a modern scientific framework, from the grassroots activities to the highest scientific level, is a strategy that deserves support as Africa seeks ways to integrate her rich traditional heritage with modern science and technology. It is hoped that this suggestion will 'bridge

FIGURE 4
THIRD WORLD ORGANIZATION FOR WOMEN IN SCIENCE: BREAKDOWN OF 271 AFRICAN MEMBERS BY DISCIPLINE



Source: TWOWS Report.

the gap' which now exists between traditional and modern scientific knowledge, and between community level and scientific institutional activities, and pave the way for making science a way of life in Africa. It could also serve to dispel the impression that S&T are new to Africa when, in fact, there is evidence to demonstrate that these areas have always been pursued in Africa until in certain periods of history, slavery and colonization halted progress and threw the continent into the 'dark ages' (Odhiambo, 1994). The greater involvement of African women in science is seen as an important means of augmenting the pool of S&T specialists and thus creating a critical mass in scientific disciplines of particular importance and relevance to Africa. It is also seen as a crucial means of integrating science and culture, now and in the future, by involving a group whose multiple roles can be used with tremendous advantage to promote scientific literacy at all levels.

When all the arguments for the greater involvement of African, and other, women in science, have been made, certain questions linger in the mind. Many people interested in the advancement of women have asked: do women have a special and unique contribution to make to the processes and application of S&T in development? Are women's perceptions of science and technology and their use different from those of men? Does the fact that most women scientists are to be found in the biological and medical fields indicate a natural concern for life, which could influence their decisions and policies in the matter of the use of science and technology in the world? These are important questions; associations like the Third World Organization for Women in Science are trying to supply answers.

One thing is clear – women, the traditional educators and transmitters of cultural values, must be at the forefront of science education, formal and informal, of research and development, in policy making and in the creation of a vision of the future of Africa in which society will be transformed for the better through the use of science.

Lydia Makhubu was appointed to her present position, as Vice-Chancellor of the University of Swaziland, in April 1988, the only woman in a comparable position in the southern Africa region. Professor Makhubu gained her BSc from what was then the Pope Pius XII College in Lesotho, an MSc in Organic Chemistry from the University of Alberta and a PhD in Medicinal Chemistry from the University of Toronto.

She has held various positions of responsibility within the university and serves on numerous international boards and advisory councils. She is currently the President of the Third World Organization for Women in Science (TWOWS). Her principal concerns are the development of tertiary education and the representation of women in technology. She maintains her interest and research effort in the field of the chemistry of natural products.

Women in science: the case of India[1]

RADHIKA RAMASUBBAN

India launched a programme of modernizing and industrializing its economy and society four decades ago, which led to a continuous expansion of institutions of higher learning in science and technology. Today, India boasts of having the largest concentration of scientific and technical personnel in the developing world. The current number of over 2 million persons with undergraduate, masters and doctoral degrees in science and technology represents a five-fold increase from the early 1950s. A little over a quarter of this number are women.

Pure science and medicine have consistently ranked high among women's preferences as subjects for advanced study. Nearly 88% of science degree holders are in pure science, 8% are in medicine and a little under 3% are in engineering/technology. However, the recent growth in the numbers of women enrolling in engineering courses shows signs of slowing and even reversing. Women's choice of subjects has followed a certain pattern: in science, they have chosen biosciences and chemistry; in engineering, electrical and electronic engineering; in technological courses, pharmaceutical technology and medical laboratory technology; and, in medicine, obstetrics and gynaecology, paediatrics, pharmacology, bacteriology/pathology, speech/hearing therapy, physiotherapy and dentistry.

Women tend to drop out of science education at the higher levels. Three-quarters leave after the first degree; just 1% complete a PhD. The same is true for engineering. Only in medicine do women continue graduate studies at higher rates.

Nearly two-thirds of working women scientists and technologists are engaged in teaching, and another one-fifth do administrative work. Only 3% are to be found in R&D. Women also have an insignificant presence in such technical jobs as quality testing, operation, maintenance and industrial production, and in higher managerial positions.

The public sector has hitherto been the largest employer of scientists and engineers/technologists. It employs five times the number of scientists taken in by the private sector and twice the number of engineers. While for women engineers, too, the public sector is the bigger employer, taking in three times the number employed by the private sector, the pattern does not hold for the sciences. Nearly 40% of women scientists are to be found in the private sector. This is a problem since it is the public sector agencies and laboratories that are the most prestigious, i.e., the Council for Scientific and Industrial Research, Indian Council of Medical Research, Indian Council of Agricultural Research, Department of Atomic Energy, and so on. Women scientists fill only 5.4% of the jobs there. In other public sector bodies that employ scientific and technical personnel (the ministries and departments of the federal government and the governments of the individual states) the proportion of women is only 3.6%, a figure lower than even the 'apex' agencies.

As against one-fifth of men scientists and engineers occupying middle and top-level positions (specified in terms of salary levels), only 8% of women figure in these levels. Again, while only 2% of men seeking jobs remain unsuccessful, among women this figure could be as high as 25%, with 15% of qualified women not even aspiring to enter the job market.

The relatively small number of women completing doctoral programmes, the low proportion of women

1. For sources see CSIR (1981), DST (1980), Government of India (1981) and University Grants Commission (1980-89, 1983-84, 1992-93) in References and further reading, p. 345.

in R&D related work, their preponderance in teaching jobs, the relative invisibility of women scientists in the apex scientific agencies, and the tendency of women scientists to be found in greater numbers in the private sector – these all have explanations that are rooted both in the contradictions that plague the state of Indian science and higher education, and in women's social obligations in Indian society.

Problems with the way higher education and scientific research are separated from each other in India combine with traditional social role expectations to inhibit women's entry into and perserverence in research careers. Despite their relatively privileged class backgrounds – urban/middle class/professional, where family financial support is accompanied by early socialization that encourages high academic achievement for girls for its own sake – women have yet to be able to overcome the extra obstacles that gender obligations create so that they can develop research careers. To begin with, family commitment to deferring the age at marriage for daughters is usually extended only until completion of a first university degree. Despite their financial and cultural access to higher education in science, therefore, women suffer a lack of autonomy in marriage decisions, an autonomy which is vital for their own control over the circumstances of their future career patterns. Since their own mobility is contingent on the requirements of their husbands' professional careers, they are ineffectively placed to seek stable careers within the national research institutions.

Additionally, teaching has always been regarded as a socially more acceptable calling for women in South Asia, due to its ethos and conditions of work being perceived as being more compatible with the combined demands of family, home and career. For women of high social status and high qualifications to opt for less well paid teaching jobs is seen as being quite in order.

Despite its long hours of work and generally more demanding nature, medicine has always been favoured as a career for women in India. Additionally, it affords prospects of self-employment. Engineering, too, is gaining prestige in women's hierarchy of preferences and recent surveys have found that women opting for engineering courses demonstrate greater independence and a more focused career orientation. Both these careers are seen as intellectually more challenging than those in other sciences, their greater social prestige makes entry difficult and the countrywide competition for admission often requires women to leave home to pursue higher study.

In summary, women are making some progress in scientific and technological careers in India, but there is a long way to go before their career expectations can equal those of their male colleagues.

Radhika Ramasubban has been working for some time in the area of history and sociology of science and technology. More recently, her work has focused on medical and public health policies and strategies in the Indian sub-continent. She has published research papers in books and periodicals in Asia, Europe and North America, and has participated extensively in seminars, symposia and professional bodies. Currently, Professor Ramasubban is one of the Vice Presidents of the Research Committee on the Sociology of Science and Technology of the International Sociological Association. She works at the Centre for Social and Technological Studies, Bombay, as a senior member of its faculty.

International players and initiatives

ELIZABETH McGREGOR AND SANDRA HARDING

KEY LANDMARKS AND PREVIOUS RECOMMENDATIONS

Gender issues in science and technology have a history of analysis and action internationally. Figure 1 sets out key conferences since 1975 at which issues of gender, science and technology and development have been debated. These issues cut across several sectors including health, energy, agriculture, the environment, education, information systems and the gender dimension of micro-enterprises. A range of previous recommendations calls upon governments to increase opportunities for women to participate in education and careers in science and technology, and sets out strategies to ensure fuller participation of women in policy and decision-making bodies. Repeatedly, issues of access to resources, information and relevant skills training appear in documents from these international fora. More recently, issues about local knowledge systems and the differential impact of science and technology on the lives of women and men have emerged.

A collation of the international documents and agreements appears in Volume I of the guidebook *Gender in Science and Technology for Sustainable and Equitable Development* (IDRC, WWVA, 1994). An accompanying summary of the evolution of recommendations over time and across science sectors is set out in *Missing Links: Gender in Science and Technology* published by Canada's International Development Research Centre as the companion book to the final report of the Gender Working Group of the United Nations Commission on Science and Technology for Development (GWG-UNCSTD, 1995*a* and *b*).

INITIATIVES IN THE UNITED NATIONS

As international institutions supported by public funding, and as potentially powerful agents for change, United Nations agencies carry considerable responsibility as models of institutional commitment to gender, science and technology. The Gender Working Group of the UNCSTD undertook, as a part of its mandate, a review of the performance of the UN agencies in this regard. With the assistance of UNIFEM, an analysis of 24 agencies was conducted to examine issues of intra-agency performance, inter-agency coordination and collaboration of UN agencies with women's non-governmental organizations in science and technology. The UNIFEM Report, *Review of UN Agency Activities in the Field of Gender, Science and Technology* (UNIFEM, 1994), contains detailed information relating to the policies, structure, staffing, programming and evaluation activities of UN agencies in gender, science and technology. Conclusions emerging from this review included the following:

1. While most agencies have a commitment to gender which is often enshrined in policy resolutions and have created gender departments, programmes and/or focal points, and while many have a strong commitment to S&T, only four agencies had clearly identifiable gender, science and technology focal points; in all cases (except UNIFEM and INSTRAW – the International Research and Training Institute for the Advancement of Women) there is a lack of policy-level recognition of the importance of gender, science and technology issues.

2. The concern of most agencies reflects conventional approaches to assisting women with gaining equal access to improved technologies. There is less emphasis on involving women in the process of technology development and very little on promoting women's increased involvement in S&T decision making or inclusion of women's perspectives in the S&T system.

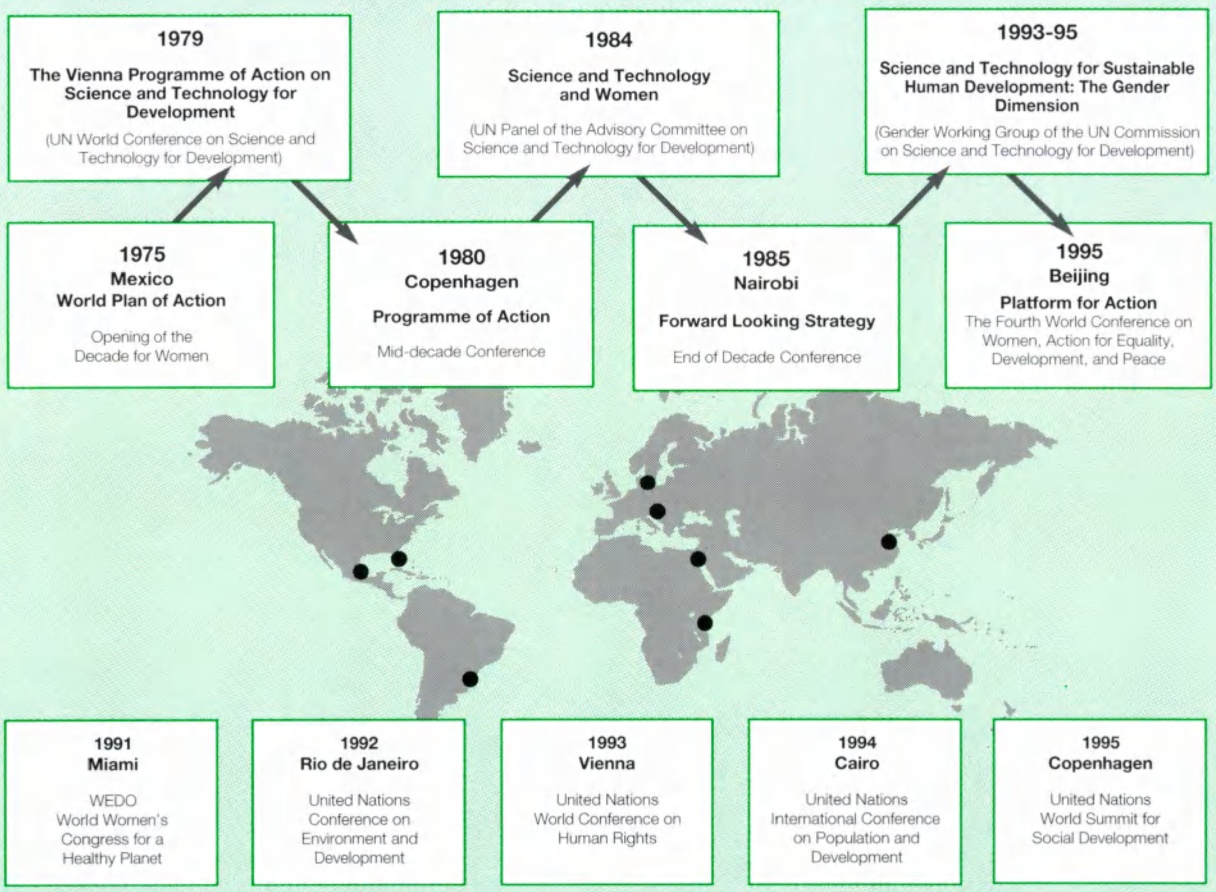
3. Intra-agency mechanisms for appraising, monitoring and evaluating gender, science and technology projects and programmes is very weak for a variety of structural, staffing and financial reasons. The result of this is that gender has not been effectively integrated into S&T activities within the UN system.

4. Although there is some evidence of inter-agency collaboration on these issues, it takes place on an *ad hoc* rather than on a coordinated and strategic basis. While there is increased recognition of the importance of learning from NGOs, few agencies have initiated mechanisms systematically to involve women's NGOs in policy and programme development, implementation or evaluation.

A second independent study was commissioned by the UNCSTD Gender Working Group to review UN corporate commitment and agency initiatives. Deliberations on this and the UNIFEM Report resulted in a set of recommendations from the Gender Working Group to the United Nations, including the following seven:

1. The UN should be required to review its current corporate policy to ensure gender, science and technology are formally incorporated into that policy. Gender and S&T specialists within each agency should prepare case studies and training materials to demonstrate how this can be done. Gender specialists should work with monitoring and evaluation and statistical staff in each UN

FIGURE 1
GENDER, SCIENCE AND TECHNOLOGY – KEY LANDMARKS



agency to establish the systematic collection of gender disaggregated data. Agencies should collaborate to ensure common methods.

2. UN agencies should actively respond to policies calling for the recruitment of professional women by establishing clear targets and timelines for the appointment of women to high-level professional posts with strategic importance to S&T. There should be explicit proactive recruitment, retention and re-entry programmes for professional women in S&T. Agencies should be required to report regularly to their governing bodies on the progress achieved and specific constraints encountered. These should review the successful experiences of agencies such as CGIAR and WHO in this regard.

3. UN agencies should incorporate gender analysis and assessment into the design and evaluation of S&T programmes and projects using practical guidelines. Although each agency has a distinctive mandate and programming approach and while, therefore, guidelines will have to be ultimately specific to each agency, a set of general guidelines should be followed by each agency. Those guidelines already developed by UNIFEM could be built upon for this purpose.

4. The UN should establish procedures to research, document, monitor and evaluate the gender impact of their S&T programming. These should include regular reporting of results and lessons learned to respective governing councils. The experiences in this area of agencies such as the International Labour Organisation (ILO), the United Nations Industrial Development Organization (UNIDO) and UNIFEM could be built upon to develop general guidelines for adaptation by other agencies. Gender and S&T specialists in each agency should work together with monitoring and evaluation units on this process.

5. The UN should give its full support to strengthening and sustaining informal methods of inter-agency networking on gender, science and technology issues. The CSTD should interact with this network in an ongoing way to ensure gender perspective and mutual support in achieving goals. The UN should also explore alternative intra-agency and inter-agency communication such as an electronic network on gender, science and technology. This network could be linked to the existing NGO network.

6. UN agencies with functions at the interface of science and technology should incorporate gender analysis into all regular programmes and provide increased regular budgetary allocations to gender units. Technical agencies should support adequate staffing of gender experts and require training of all staff in gender analysis to ensure full incorporation of gender into their regular programme of work.

7. The UN should recognize the value of collaboration with NGOs and expand formal partnerships and support with NGOs at the levels of policy advice, assistance with design and implementation of technical cooperation programmes and evaluation. Models such as those being developed by CGIAR and UNHCR could be explored and approaches suitable for each agency identified. Partnerships with over 650 NGOs active in gender, science and technology should be forged. The NGO Once and Future Action Network should be supported and UN focal points involved in the activities of the consortium.

Gender, science and technology in the United Nations

MARILYN CARR[1]

The Fourth World Conference on Women has generally raised interest in gender issues within UN agencies and increased the resources available for women-related activities. But how much of this focuses on gender, science and technology? There was certainly a great deal said about the subject in the 1985 Forward Looking Strategies. How far has the UN been able to assist in implementing S&T recommendations? What are the policies, programmes and trends in the various agencies, and what are the problems being encountered?

These are some of the questions asked in a survey of 24 agencies located in Bangkok, Paris, Rome, Vienna, Geneva, New York and Washington. The survey was undertaken by UNIFEM in February 1994 at the request of the Gender Working Group of the United Nations Commission on Science and Technology for Development. The survey covered: corporate policy on gender, science and technology; mechanisms for implementing and evaluating gender, science and technology programmes; types of activities undertaken (with specific examples to indicate approach); linkages between UN agencies and with NGOs; and plans for gender, science and technology at the Beijing Conference and beyond.

The amount of information collected was impressive, with most agencies able easily to provide several examples of what they have done. When it comes to corporate policy, however, this is often expressed in vague terms of increasing women's access to technology, or increasing girls' access to science education, or is not defined at all at the policy level. In addition, while many agencies believe that all of their S&T programmes benefit both men and women equally, monitoring and evaluation systems are rarely able to provide proof of this. Most people agreed that a better monitoring and evaluation system would enable us really to measure what progress has been made in this field.

With respect to types of activity, while the majority of projects are still in the conventional categories of disseminating technologies to women farmers and entrepreneurs, and of increasing women's access to S&T education and to the formal S&T sector, there is a noticeable increase in interest in supporting women's indigenous technical knowledge, highlighting the role of women innovators, and encouraging linkages between professional women scientists and engineers and grassroots women. This is an important trend that was further advocated in Beijing through the Once and Future Pavilion and the NGO Forum.

With so much information available in individual agencies, and with so much interesting work going on in a host of NGOs, a sharing of experiences can be very helpful. The UN agencies are already benefiting from the distribution of the survey document, and many are being increasingly involved with the Once and Future Action Network (OFAN) in the planning of the OFAN S&T Pavilion. It is hoped this experience of working together on gender, science and technology issues will form a strong and lasting network of UN agencies and NGOs well beyond Beijing.

Recommendations relating to corporate policy, evaluation mechanisms and networking, as well as to the need to recruit more women to high-level technical positions in the agencies, are being made by the Gender Working Group of UNCSTD. Hopefully, these will assist in strengthening the UN's work in this important area.

All agencies can do more to increase women's access to science and technology. All also have an important role to play in helping to advocate the concept of women shifting the S&T mainstream in a more people-centred direction.

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NGOs: The Once and Future Action Network

JOSEPHINE BEOKU-BETTS[1]

The involvement of non-governmental organizations in raising public awareness of gender issues in science and technology has rapidly developed over the past decade. With a growing understanding of the effects of global economic restructuring, rapid technological changes, persistent poverty and widespread environmental degradation, these groups, which range from grassroots level development organizations to professional associations of women scientists, challenge current development paradigms and advocate fundamentally new ethics, programmes and development practices.

For many concerned NGOs, the needs of the majority of the world's women have yet to be adequately addressed, even though the importance of science and technology in women's lives has been recognized in several world conferences. Though some progress has been made, society's assumptions that women are non-scientific and non-technological forestall any proper understanding of women's needs in the design and implementation of programmes. As women continue to be perceived as passive recipients of S&T, there is a lack of recognition or validation of the wealth of scientific and technological knowledge (both formal and non-formal) they contribute to social and environmental well-being. A result is that research and development resources in food production, food processing, rural water supply and renewable energy resources, all of which are major priorities for women, remain highly inadequate. Limited opportunities for training (both formal and non-formal), employment and leadership roles for women in science and technology also remain critical concerns. Concerned NGOs challenge these approaches to development and seek to create more holistic, people-centred and environmentally sustainable approaches to scientific practice. They seek to reclaim women's indigenous scientific and technical knowledge and to foster an environment in which women can actively participate in conceptualizing and designing science and technology development strategies.

In 1992 UNIFEM and the International Women's Tribune Centre began a process of contacting organizations and individuals involved in gender, science and technology, with a view to planning a strategy for highlighting science and technology at the Fourth World Conference on Women in Beijing, China, in 1995. They felt that the unique opportunities offered by the Conference and the parallel NGO Forum to bring these issues to the forefront of the women's development agenda should be utilized to influence the 1995 Platform for Action (the major policy document endorsed by UN Member States to promote the advancement of women).

The Once and Future Action Network (OFAN), a group of over 40 International NGOs active in gender, science and technology, has grown out of this initiative. Its purpose is to accomplish the following:

- To promote equal access for girls and women in scientific and technological arenas, including promoting educational and scientific literacy for girls, equal access for technological training at all levels and involvement of women in scientific and technological roles throughout their lives.

- To recognize the value of existing skills and expertise and promote linkages between formal science and women's indigenous scientific knowledge.

- To strengthen the roles of women so that they are able to guide the reallocation of resources in science and technology research and practice, and to re-assess the directions, goals and ethics of research and development.

- To effect social change by creating an environment which enables the benefits of women's scientific and technological knowledge to be shared fully and used as a common heritage for all.

OFAN's membership is constituted of organizations ranging from professional associations of women scientists to development NGOs working with women at the grassroots level.

Although the combined experience and resources of the OFAN membership provide a sound framework to foster the network's vision in tangible ways, individual NGO involvement in S&T at both formal and non-formal levels predates the existence of OFAN and similar ventures. For example, the International Federation of Institutes for Advanced Studies (IFIAS), the Third World Organization for Women in Science (TWOWS), the World Women's Veterinary Association (WWVA) and Approtech-Asia developed databases and directories on professional women in science and technology, while the Intermediate Technology Group (IT), IFIAS and WWVA documented women's scientific innovations at the non-formal level. Similarly, scientific associations such as Gender, Science and Technology (GASAT), the American Association for the Advancement of Science (AAAS) and the Forum for African Women Educationalists (FAWE) have conducted studies to examine barriers and constraints to women's entry into the sciences and to promotion and leadership positions in scientific careers. The importance of role models and mentoring of young women scientists has also been emphasized by scientific associations in the Philippines, Ghana and the USA, through organized lectures, summer camps and science fairs. Finally, development NGOs such as the IWTC and the World YWCA Energy and Environment desk, have over the years done much to demystify and popularize science and technology through publications and training programmes.

A number of long- and short-term strategies have been adopted by the Once and Future Action Network to promote collaboration, capacity building and advocacy among its members. The 1992 UNIFEM/IWTC survey on which organizations were involved in gender, science and technology activities, produced a directory on *Who's Doing What in Science and Technology*. This directory has been used as a resource guide and networking tool. The UN has also called on the expertise of OFAN's diverse membership to provide advice on the gender implications of science and technology as they relate to women in the Platform for Action. It organized workshops on science and technology at UN preparatory meetings and NGO consultations regionally and internationally. OFAN succeeded in having these issues emphasized in some of the regional action plans, especially for the Africa region. OFAN also produces a quarterly newsletter, engages in electronic conferences and conducts meetings with similar interest groups in local communities.

The Fourth World Conference on Women and the parallel NGO Forum in Beijing provided an opportunity to highlight OFAN's vision of a more sustainable and people-centred approach to science and technology at an event at the NGO Forum called the Once and Future Pavilion. The Pavilion was an interactive event, making visible a broad spectrum of activities which highlighted the contributions women could make in redirecting science and technology and in setting a new agenda for science and technology in the future. The Pavilion provided a forum to pose questions and challenges, to network, to share ideas and strategies, and to start a re-envisioning process that could be implemented in innovative ways locally, regionally and internationally beyond Beijing.

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The United Nations Commission on Science and Technology for Development

GENDER WORKING GROUP 1993-95

OBJECTIVE

The Gender Working Group was formed in 1993 with the objective of making recommendations to national governments for individual country actions; and recommendations to the Economic and Social Council (ECOSOC) for reforms required in the UN system on 'gender, science and technology'.

PROCESS

A report was prepared over a two-year course of debates by a working group of eight male commissioners and eight women advisers. Twelve consultants and over 17 NGOs active in gender and science and technology and development were involved in the process with 24 United Nations agencies. The process was highly consultative and participatory, inviting input from over 100 S&T institutions internationally.

KEY FINDINGS

■ Gender inequity in education and careers in science and technology
There are serious obstacles to girls' and women's participation in scientific and technical education and careers, and there are relatively few women in science and technology decision-making bodies and advisory boards.

■ The gender specific nature of technical change
Technical change aimed at benefiting people in rural areas in developing countries appears to have benefited men's lives more than women's lives.

It was the underpinning premise of the Group that development is gender specific. That is, women and men have different roles and responsibilities in society and perform different tasks. Therefore, to ensure that science and technology benefit all members of society, purposeful policy attention must be paid to the respective needs and interests of men and women equitably.

■ Transformative actions
Seven issues on which transformative actions are both necessary and feasible were identified, and options for action were outlined for each. The seven were:

1. Gender equity in science and technology education.
2. Removing the obstacles to women in scientific and technological careers.
3. Making science responsive to the needs of society: the gender dimension.
4. Making science and technology decision making more gender aware.
5. Relating better with local knowledge systems.
6. Addressing ethical issues in science and technology: the gender dimension.
7. Improving the collection of gender disaggregated data for policy makers.

■ Declaration of Intent
A Declaration of Intent consisting of six goals for equity in science and technology was formulated and all governments were invited to subscribe to this Declaration and to establish an *ad hoc* committee to formulate national action plans for its implementation.

THE UNITED NATIONS REVIEW

An extensive review of the performance of the UN system in gender, science and technology resulted in a set of recommendations for transmission to ECOSOC.

Women, science and technology on the Internet

BEV CHATAWAY[1]

The type and variety of information resources available electronically via the Internet and other networks is expanding at a phenomenal rate. Some resources on gender, science and technology as of April 1995 include:

DISCUSSION GROUPS

A variety of policy discussion groups are available internationally for those subscribers wishing to tap into global exchanges with experts sharing similar interests. These include:

EDUCOM-W is a moderated discussion list centering on issues in technology and education of interest to women. Send subscription messages to:
LISTSERV@BITNIC.EDUCOM.EDU

FIST is an unmoderated list for discussion of feminism and science and technology. Send subscription messages to:
LISTSERV@DAWN.HAMPSHIRE.EDU

WISENET is an electronic discussion group covering topics relating to women in science, engineering and mathematics. Send subscription messages to:
LISTSERV@UICVM.UIC.EDU

WITI is a discussion group of the International Network of Women in Technology. Send subscription messages to:
WITI@CUP.PORTAL.COM

INFORMATION SITES

Subscribers can tap into an emerging range of international information sites on the Internet including:

■ Women in technology

The International Network of Women in Technology is a professional association of women representing a diversity of disciplines in technology organizations. This site includes information about WITI, its organization and conferences.
HTTP://WWW.CAREERMOSAIC.COM/CM/WITI

■ Women in Sciences and Engineering

This site includes a 'women in sciences reading room' with references on women in science from antiquity to the present day.
HTTP://TWEEDLEDEE.UCSB.EDU/ KRIS/WIS.HTML

■ Women and minorities in science and engineering

This includes listings of organizations, other information sites and full text documents related to this topic.
HTTP://WWW.A1.MIT.EDU/PEOPLE/ELLENS/GENDER/WOM AND MIN.HTML

■ Organizations encouraging women in science and engineering

The US National Research Council's Committee on Women in Science and Engineering (CWSE) first met in 1991. This site includes a 'resource list of US organizations of and for women in science'.
HTTP://XERXES.NAS.EDU:70/1/CWSE

■ Women in science project at Dartmouth College

This project was created to encourage young women to pursue their interests in science.
HTTP://MMM.DARTMOUTH.EDU/PAGES/WISKIT.HTML

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The contributors to *The Gender Dimension of Science and Technology* hope that the necessarily compressed and highly selective reviews, overviews and 'snapshots' of substantive issues that could be presented here will stimulate debate, specific studies and action on these urgent issues.

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Elizabeth McGregor is Director of Studies, Gender Working Group, United Nations Commission on Science and Technology for Development and Senior Policy Analyst to the Science Advisor of the President, International Development Research Centre, Canada. From 1991 to 1993 Dr McGregor was Director of Canada's national Task Force on Science and Technology for Competitiveness. Following graduate field work in South America, she was posted to the field and Headquarters of the UN Food and Agriculture Organization in the 1970s. Returning to undertake veterinary medicine studies, she served as Director of International Programs to the Ontario Veterinary College and subsequently worked in policy for the Canadian Government. Dr McGregor is founder of the World Women's Veterinary Association, an international NGO working in policy and field projects with women and children in agriculture. Recipient of the 1993 Distinguished Award for Service by the American WVA, she served on the science and technology NGO planning consortium for the 1995 Fourth World Conference on Women.

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Women in modern scientific research: A historical overview

PNINA G. ABIR-AM

If 'science is the mode of cognition of industrial society', as a leading anthropologist stated, then the marginal position of women in science, from the Scientific Revolution of the 17th century, until the late 20th century's revolution in information and biotechnology, may provide crucial insights into the increasingly international social order of modern society. Indeed, science has often been viewed as a major force for modernity. But if women, or half of the population, are still consistently under-represented in science, can we conclude that gender equality in science is a matter for post-modernity only?

What are the implications of women's almost total exclusion from science over four centuries for the relationship between science and society, as well as for the relationship between the genders, a relationship that is continuously legitimized by appeals to science's undisputed cultural hegemony? How can science claim that as an institution, it has ever been uniquely suited for the production of objective knowledge, when the knowledge it claims has so rarely reflected the world view of half of the population, even when eminently qualified? Why did the practitioners of science invariably use its privileged epistemological status to circulate an imagery of gender and women that further reinforced the gender hierarchy in the social and political order at large?

In addressing these questions, it is useful to examine the role of women in scientific research according to five, interdependent, criteria: historicity; disciplinarity; nationality; familial status; and gender consciousness (Abir-Am and Outram, 1987). But it must first be emphasized that our perception of the history of women in science is affected not only by the actual historical participation of women in science, or surviving records of it, but also by the present distribution of gender consciousness among historians of science, scientists, science journalists and other authors reflecting on science. The perceptions of all these categories of authors are further influenced not only by the relative prevalence of multi-culturalist ideologies, but also by the centrality of an 'identity politics' (or politics guided chiefly by issues of ethnicity, race, gender or class) in both civic society and the academic sector. This was particularly so during the 1980s, when most of the scholarly excavation of women's role in science began (see the references and further reading for peaks of writings on women and science in the 1980s).

International policy with regard to gender, for example the UN Decade on Women in Development (1975-85), while sensitizing public and academic opinion to the politics of gender worldwide, has also played a major role in producing a radical discourse on gender, women and the scientific culture of late 20th century societies. Because these various forces have interacted more forcefully and on a larger scale in the context of US domestic politics and academic scholarship (Hollinger, 1993), much of current scholarship on women, gender and science reflects implicitly or explicitly the standpoint of the American experience. At the same time, this plausible source of bias is counteracted by the rapid increase, also in the 1980s, in affordable international communication, especially by fax and electronic mail, so that both national boundaries and temporal distances are now less relevant.

HISTORICITY

The participation of women in the scientific enterprise, much as any other aspect of science, has varied through history, though not in a linear, progressive manner. In the 17th century, a period during which the social organization of science was created (Ben-David, 1971, 1984) aristocratic women were active as both patrons and interlocutors of many of the rising stars in natural philosophy. Continuing the tradition of Renaissance courts, women of the ruling nobility participated in that period's fascination with the new science (Ogilvie, 1986; Schiebinger, 1989). For example, the Grand Duchess Cristina of Tuscany corresponded with Galileo; Princess Caroline of Wales corresponded with Leibnitz and coordinated his contacts in England, especially his debate with Newton via the agency of Bishop Clarke; Queen Christina of Sweden organized her Academy of Science together with her former tutor, Descartes. Margaret Cavendish (1623-73), the first Duchess of Newcastle, published many treatises on science (*ibid.*).

At the same time, the academies and societies that became the institutional centres of the new science, such as the *Académie des Sciences* in Paris and the Royal Society of London, specifically excluded women, however qualified. This stemmed in part from the fact that the sinecures provided by these institutions were crucial for the rising class of scientists who were of middle class origins and needed an income; and in part because the ideology of the new science, especially as framed by Francis Bacon, construed science as a (masculine) conquest of (feminine) nature (Merchant, 1980; Keller, 1985; Schiebinger, 1989). The rhetoric of 17th century science is replete with gender metaphors, while further seeking to displace female-based forms of social power, both materially and symbolically, that ranged from female dominated courts and salons to various 'crafts' such as astronomy, entomology and midwifery. Women with scientific interests had to retreat into women's academies, to limit themselves to the practice of 'crafts', or to depend upon an enlightened male relative for their access to science (e.g. Caroline Herschel (1750-1848), discoverer of eight comets, sister and aunt of Britain's Astronomers Royal).

Despite various exceptions throughout the 18th century, such as the Marquise Emilie du Chatelet (1706-49), best known as the translator of Newton and a collaborator of Voltaire, who wrote several books on physics, or Laura Bassi (1711-78), a professor of physics at the University of Bologna, women's access to the practice of science remained derivative of their familial positions, as spouses or daughters of men of science. They worked in supporting activities, as collectors, illustrators, translators and hostesses of cultural events, and did so from a domestic base, as most of science was then done in a domestic context by both men and women (Abir-Am and Outram, 1987: chapters 1 and 2). The scientific contributions of such women were habitually submerged in the production of their household, a production which was often credited to its patriarchal head.

By the mid-19th century, the doctrine of separate spheres acquired hegemony, resulting in a dichotomy between a public domain with which science came to be increasingly associated, as a result of increasing professionalization, and a private or domestic domain with which women became increasingly associated. More specifically, the emergence of the family as an emotional unit, i.e. not a 'mere' legal and economic unit, resonated with increases in the life expectancy of children and with the spread of a bourgeoisie in which women's economic contributions were no longer needed. These changes in family and class ideology precipitated the classical dilemma between marriage and career for women, further signalling a supposed incompatibility between marriage and science (*ibid.*: chapters 3-6).

Despite some modest gains in women's access to science towards the end of the 19th century, the doctrine of separate spheres continued to shape social and cultural attitudes. Women remained largely associated with the private domain, just at the time that science shifted its institutional basis to the public domain, while increasingly occupying a socially prominent position. Numerous literary and scientific writings elaborated on the supposed incompatibility of women and intellectual pursuits. Throughout the 19th century, the age of disciplinary differentiation and national associations for the advancement of science, women remained on the margins of increasingly professionalized science. As late as 1921 the University of Cambridge voted to exclude women from formal degrees, an exclusion that obtained until after the Second World War.

Considerable change in terms of new role models for women in science took place in the last third of the 19th century, with the advent of women's colleges, as well as with the universities' occasional willingness to

Photo: © Harlingue-Viollet.

Marie Curie and her daughter Irène in their Paris laboratory.

grant degrees to women, especially women of foreign nationalities who were expected to practise in their countries of origin (e.g. the large contingent of Russian women medical students in Switzerland (Bonner, 1992), or American women doctors and physiologists in France, Britain and Germany (Rossiter, 1982). Several women achieved fame while pursuing scientific careers from a variety of institutional bases, such as women's colleges (e.g. astronomer Maria Mitchell (1818-82) at Vassar College in New York State); scientific societies (e.g. anthropologist Clemence Royer (1830-1902), who was the only woman member of the *Société d'Anthropologie* in Paris; and peripheral, new universities (e.g. Sofia Kovalevskaia (1850-91) who became the first woman professor of mathematics in modern times, at the University of Stockholm) (Abir-Am and Outram, 1987: chapters 7-9). Many more women became active in observational fields, such as astronomy, ornithology and primatology, that still accepted many 'amateurs', or fields such as botany and medicine, which further resonated with the cultural imagery of women and gender at the time (Haraway, 1989; Jordanova, 1989; Schiebinger, 1989).

The 20th century saw a more profound, though slow and gradual, rapprochement between women and science. Until the affirmative action legislation of the 1970s, the entry of women into science largely followed the tokenist model of a few heroic pioneers, such as the twice Nobel laureate (1903, 1911) chemical physicist Marie Sklodowska Curie (1867-1934) who became a professor at the Sorbonne and Director of the Radium Research Institute in Paris; or the theoretical physicist Lise Meitner (1878-1968) who served as head of a division in the Kaiser Wilhelm Institute for Radio-chemistry in inter-war Berlin. Both Curie and Meitner, who began their careers prior to women's suffrage in the aftermath of the First World War (having served their countries, France and Austria respectively, during that war), broke the social stereotype of women's supposed inability to do science, especially 'hard' science such as physics. They opened the door to small numbers of women scientists, while further symbolizing two of the major avenues for women's participation in science: marriage to one's collaborator (as in Curie's case: for many other collaborative couples see Pycior, Slack and Abir-Am, 1995); or devoting one's whole life to science under the patronage of enlightened men scientists, as in Meitner's case (for additional examples see Abir-Am and Outram, 1987; Ainley, 1990; Kass-Simon and Farnes, 1990; see also below, pp. 353-4).

Throughout the first two-thirds of the 20th century science remained largely restricted for women. While research institutes accommodated a certain number of women, elite universities and national academies long remained bastions of gender discrimination (Rossiter, 1982, 1995). The first woman to become President of the French Academy of Sciences, biochemist Marianne Grunberg-Manago (1921-) was elected in October 1994. The Royal Society began to elect women Fellows only after the Second World War while retaining, together with the US National Academy of Sciences, unusually small numbers of women members.


Photo: Lotte Meitner-Graf, London.

Dorothy Hodgkin, at the time of her award of the Nobel Prize for Chemistry 1964.

Pioneering women of science in the 20th century include Dorothy Wrinch (1894-1976), the first woman to receive a DSc from Oxford University (1929), the first nominee since the First World War for fellowship in the Royal Society and a Nobel Prize nominee; Dame Mary Cartwright (1900-) who in 1935 became the first woman lecturer in mathematics at Cambridge University; crystallographer Kathleen Lonsdale (1903-73) and microbiologist Marjorie Stephenson (1880-1950), the first women to be elected to the Royal Society (in 1945); Cecilia Payne Gaposhkin (1900-79), the first woman to become professor of astronomy at Harvard (in 1955); and the Nobel laureates, Marie Curie (1903, 1911), Irene Joliot-Curie (1935), Gerty Radnitz Cori (1947), Maria Goeppert-Mayer (1963), Dorothy Hodgkin (1964), Rosalyn Yalow (1977), Barbara McClintock (1983), Rita Levi-Montalcini (1986) and Gertrude Elion (1988).

Women were eventually able to gain access to scientific education and careers in larger numbers but only after the rise of the women's liberation movement in the 1970s as a major political and ideological force worldwide, but especially in the USA. And only late in the 1980s did the under-representation of women in science finally become articulated as a problem of national priority for both science policy and social policy. This occurred partly as a result of the consolidation of a generation of struggle for gender equality; partly because of an urgent need to recruit and retain scientists within a rapidly changing demographic structure; and partly because of considerations of global competitiveness in the emerging new, science and technology based, economic world order that has come to replace the previous super-power confrontation of the Cold War era (Cozzens, Healey, Rip and Ziman, 1990; Abir-Am, 1992). Yet despite the overall marginality of women's experience in science across history, a certain variation obtained across its disciplinary sub-cultures, with women finding more opportunities in some disciplines rather than others.

DISCIPLINARITY

Important variations, often of a surprising nature, exist across the observational, experimental and theoretical sciences. Traditionally women found acceptance in larger numbers in observational sciences, most notably astronomy, botany, ornithology and anthropology. These disciplines always required the collecting of numerous specimens, while tolerating 'amateurs' of both sexes. They were also conducive to the sharing of observational time and space by collaborative couples, a social institution that enabled many women and men to combine work and personal life under socially acceptable circumstances (Abir-Am and Outram, 1987, especially chapters 4-6; Pycior, Slack and Abir-Am, 1995). Yet the relative prevalence of women in observational sciences did not seem to lead to special peaks of achievement, as implied in *Little Science, Big Science* (Price, 1963); obviously, gender defies simplistic models of scientific change.

By contrast, the most accomplished women, at least if judged by criteria such as having made major

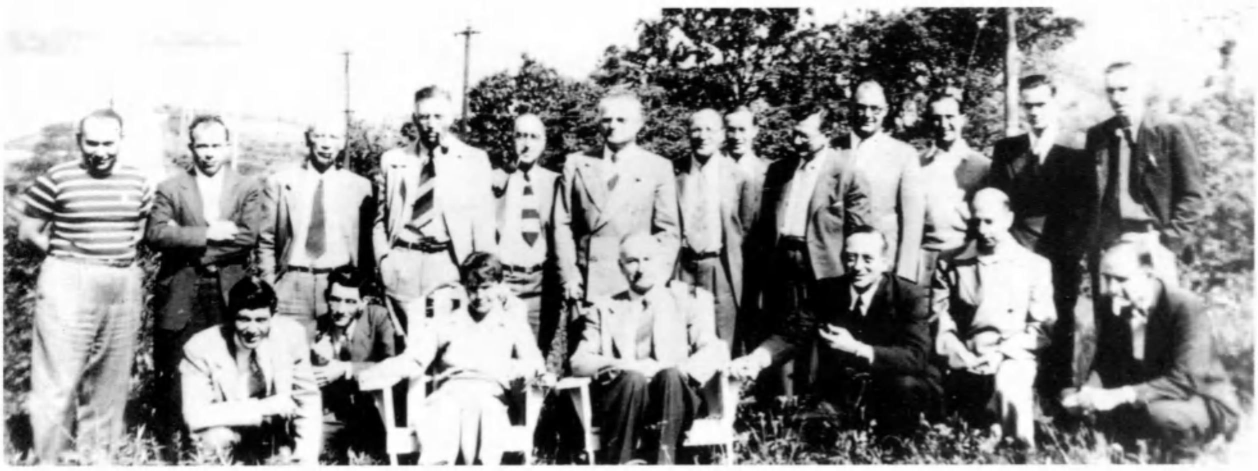
Photo: American Philosophical Society.

A young Barbara McClintock surrounded by her peers. The gender balance speaks for itself.

discoveries, belonged to the experimental sciences, often to the so-called 'hard' sciences, or to fields in which there were very few women. Examples include the discoveries of natural and artificial radioactivity, made by Marie and Pierre Curie, and Irene and Frederic Joliot-Curie, respectively, in chemical physics; the interpretation of atomic fission by Lise Meitner in atomic physics; the solution of biomedically active compounds such as the complex organic molecules of penicillin, vitamin B-12, and insulin by Dorothy Hodgkin and her teams in X-ray crystallography; the discovery of 'jumping genes' by Barbara McClintock in genetics; the development of the radioimmunoassay technique by Rosalyn Yalow; the discovery of the nerve growth factor, or NGF, in experimental neuroembryology by Rita Levi-Montalcini. These are all examples of major discoveries, rewarded (except for the oversight *vis-à-vis* Meitner, a theoretician) by Nobel Prizes, and made by women in experimental fields which had relatively few women.

The innovative work of Sofia Kovalevskaia (1850-91), Lise Meitner (1878-1968), Dorothy Wrinch (1894-1976) or Maria Goeppert-Mayer (1906-72) suggests a profile of major achievement by women in theoretical fields despite numerical scarcity. The question thus persists as to why women have tended historically to concentrate in the least prestigious disciplines, where barriers were lower, despite the greater potential for rewards in the more prestigious fields.

One possible answer could be that observational and theoretical sciences are less demanding in terms of rigid time and less dependent on intense apprenticeship with 'technical bottlenecks' such as traditional male mastery of scientific instruments, as well as being more compatible with women's familial responsibilities which often meant less time for work in the laboratory (see below).

To this day, the distribution of women scientists across disciplines is skewed while reflecting an historical accumulation of cultural stereotypes. These historically contingent and irrelevant stereotypes are further sustained by the ongoing distribution of professional power within each discipline. Paradoxically, these stereotypes are particularly evident in medicine, a field compatible with the cultural image of women as nurturers, yet one which displays strong gender stratification across specialties with women often concentrating in paediatrics, obstetrics and psychiatry.

NATIONALITY

The USA, UK, France, Russia and Canada account for most of the activity of women in science for which major historical studies exist (e.g. Rossiter, 1982,

Rita Levi-Montalcini, joint-winner of the 1986 Nobel Prize for Physiology or Medicine for her work on growth factors.

1995; Koblitz, 1983, 1993; Ogilvie, 1986, 1991; Abir-Am and Outram, 1987; Haraway, 1989; Schiebinger, 1989; Ainley, 1990; Kass-Simon and Farnes, 1990; Pycior, Slack and Abir-Am, 1995). More systematic historical studies of women scientists in Central and Eastern Europe, Central and South America and Asia, as well as other regions, are needed in order better to evaluate the role of national context, and of nationalism as an ideology (Greenfeld, 1992), in shaping the careers and opportunities of women scientists. A rare example is the Kovalevskaia Fund, directed by Ann Hibner Koblitz of Hartwick College, New York State, which promotes interest in the history of women in science in Third World countries, e.g. Cuba, Viet Nam and Mexico.

One of the most striking findings of historical scholarship on women in science pertains to the prevalence of cross-national migration. Many outstanding women scientists, often Nobel laureates, had a background of cross-national migration. Examples include mathematician Sofia Kovalevskaia (from Russia to Germany to Sweden); chemical physicist Marie Curie (from Poland to France); atomic physicist Lise Meitner (from Austria to Germany to Sweden to the UK); biochemist Gerty Radnitz Cori (from Czechoslovakia and Austria to the USA; theoretical chemist Maria Goeppert-Mayer (from Germany to the USA); cell biologist Rita Levi-Montalcini (from Italy to the USA and back to Italy); immunologist Maria de Souza (from Portugal to the UK and USA, and back to Portugal).

Of course, the large-scale intellectual migration induced by the rise of fascist regimes in Central Europe in the 1930s included many women scientists, for example, Salomee Waeltsch (1907-), a developmental geneticist who received the 1994 National Medal of Science from President Clinton.

These and other examples, most notably the large contingent of Russian women medical students in Switzerland and American women biologists in Central Europe at the turn of the century, suggest that cross-national migration relaxes national-cultural codes of social and gender control, a control which has historically restricted women's access to science through discrimination in national systems of education. Yet, in all historically informed case studies, strong mentorship by one or more prominent male scientists in the new country was necessary to secure a position for the foreign woman scientist in question. The scientific creativity deriving from such dual, cross-cultural and cross-gender collaboration remains to be further explored for both women and men scientists.

FAMILIAL STATUS

The doctrine of separate spheres, a pillar of social control and gender hierarchy since the mid-19th century, has greatly affected the participation of women in science, by positing a supposed contradiction between their familial and career responsibilities. Until the 1970s, many women scientists felt compelled to choose between a career as a scientist and marriage. For example, Nobel prize winners Barbara McClintock (1900-92, geneticist, laureate in 1983) and Rita Levi-Montalcini (1909-, cell biologist, laureate in 1986) deliberately chose to remain single so as to be able to devote their entire lives to science. Indeed, single women appeared to predominate in disciplines such as medicine, botany, ornithology and astronomy; often they established 'fictitious families' by sharing living arrangements with other women, even adopting children (see Abir-Am and Outram, 1987: chapters 3-6). The fact that widowhood appeared to be helpful to the careers of women in various fields (*ibid.*: chapters 5, 8, 9) suggests that the pervasive social role of women as wives and mothers has traditionally functioned as an impediment to fulfilling their scientific vocations.

Women scientists who did marry engaged in various modifications of traditional marital life. One of the most prevalent choices was that of a collaborative marriage to a colleague in the same field. Even though almost always priority was given to the husband's career, there was still room for scientific activity for the female spouse. While collaborative activity with their husbands appears to have shielded some women scientists from total invisibility, it invariably tended to project their work as being derivative of their husbands', implying a necessary spillover from their legal, economic and social status as the dependent spouse (see the 24 case studies of collaborative couples in Pycior, Slack and Abir-Am, 1995).

Parenting styles and childcare patterns varied greatly among women scientists of historical note. While some women in collaborative couples had no children at all (nurturing a quasi-egalitarian relationship may have been as demanding as an actual child, *ibid.*: chapters 5, 6, 15); other women scientists had primary responsibility for childcare, a task they often fulfilled while ingeniously recruiting family, friends, even colleagues (*ibid.*, especially chapter 17 on Margaret Mead and the Myrdals). A few others were able to afford paid childcare providers; more rarely, women received grants for childcare.

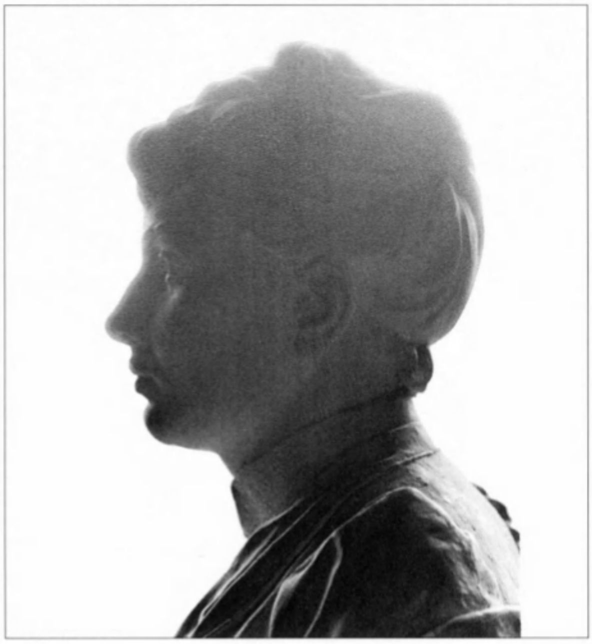

Photo: Angela Wanglert, Stockholm.

Bust of Sofia Kovalevskaia, the first woman professor of mathematics in modern times.

As these historical case studies suggest, the problem of childcare, or rather the lack of affordable quality childcare, has continued to affect women's ability to pursue scientific careers effectively, whether at the turn of the century or nowadays, a century later.

GENDER CONSCIOUSNESS

The question persists whether pioneering women scientists were instrumental in promoting similar opportunities for other women as well as raising the consciousness of both women and men scientists with regard to the gender related barriers operating in a supposedly meritocratic institution. A related question is whether the reflection of women scientists on gender and science found expression either in correcting the gender bias in scientific knowledge, most notably in 'anthropomorphic' disciplines such as primatology, reproductive biology or neurobiology; or in political activism such as increasing female scientific literacy and representation in academia (Haraway, 1989; Hubbard, 1990).

Notable women scientists who both pioneered positions for women in 19th century scientific organizations and colleges, and were politically and literarily engaged in the cause of women's liberation, include: Maria Mitchell, who educated a whole generation of American women astronomers and stood for women's political rights; Sofia Kovalevskaia who wrote novels promoting revolutionary activity for both women and men; and Clemence Royer who wrote both professional and popular treatises on evolution to combat its socially devastating view of women as 'non-evolving' members of the species. In contrast, in the 20th century the political voices of women scientists were relatively modest, as befitted their lack of a 'critical mass'. Even the reformist activist Dame Kathleen Lonsdale took up the cause of women in science only in the 1970s when the women's liberation movement was already under way.

CONCLUSIONS

Despite numerous gains, the position of women scientists remains ambiguous. Still a numerical minority, though no longer marginal and enjoying increasing visibility, women remain torn between the supposedly universalistic prerogatives of their scientific careers and the supposedly more partisan concerns with the cause of gender equality in both science and society. As with other problems of social and political inequality, the cause of women in science received a big boost in the late 1980s when it became a 'mainstream' problem of US science policy. Mobilizing women suddenly became a potential solution to the problem of shortages in scientific labour and hence to international competitiveness.

Despite the enlightened activities of various individual men scientists, and the increasing adaptation of scientific institutions to the political demands of gender equality, science has not shown itself, despite its pretence to objectivity and meritocracy, to be different from other social institutions more explicitly concerned with maintaining social control through gender hierarchy. Resistance to sharing the power of science with its women practitioners has remained high. Despite various measures congruent with the spirit of affirmative action, science did not seek to dismantle, through systematic or explicitly corrective policies, the social practices and consequences of gender hierarchy in the society and culture that produce its labour pool and shape the world view of its practitioners. Let us hope that the soon-to-arrive 21st century will inaugurate a new era of gender equality in both science and society.

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