Chapter 5 Science and Technology

Science education, in the broad sense…is a fundamental prerequisite for democracy and for ensuring sustainable development.

Declaration on Science and the Use of Scientific Knowledge,
World Conference on Science, Budapest, 2 July 1999

A Worldwide Issue

Science and technology advances are transforming the world at an astonishing rate. Developments in computing and communications, in particular, are helping to accelerate these changes. Organizations in even the most advanced economies struggle to keep up, while developing countries face serious threats, as well as some new opportunities.

The recent World Conference on Science—the first such conference in 20 years—took place as the Task Force was drafting this report. The Task Force warmly welcomes both the Declaration on Science and the Use of Scientific Knowledge and the accompanying Framework for Action, which reflects and deepens many of the themes outlined below. In particular, we embrace the framework's clear and unambiguous call that "governments should accord the highest priority to improving science education at all levels" and should work closely in this endeavor with the private sector and civil society.

Our emphasis is narrower than that of the Conference: higher education is, we believe, an absolute and irreducible prerequisite to developing a strong science and technology base. We balance this interest in science with a call for increased priority for general education (Chapter 6). Tomorrow's world will demand highly qualified specialists and increasingly flexible generalists. Higher education needs to be ready to meet both these demands.

Background

The North–South scientific gap is large and growing—in part due to the very nature of scientific and technological advances in the computing age. Further research will be required to quantify the extent of the gap, but there is enough evidence to show that it is huge.

For example, on a *per capita* basis developed countries have nearly ten times as many research and development scientists and technicians as developing countries (3.8 versus 0.4 per 1,000). They have a much higher share of their populations studying science at the tertiary level, principally due to substantially greater enrollment rates. Further, they are spending some 2 percent of GDP on R&D, compared to a rate of 0.5 percent or less in most developing countries. Western Europe, North America, Japan, and the newly industrialized East Asian countries account for 84 percent of scientific articles published. These regions also provide more than 97 percent of all new patents registered in Europe and the United States.

Science and technology have direct impacts on society (Box 5)—and such impacts can translate directly into economic growth. A well-developed higher education sector is fundamental here: it allows countries to generate new scientific knowledge, to wisely select and implement existing technologies, and to effectively adapt them to local circumstances. To achieve these tasks, higher education science and technology badly needs more investment and more efficient allocation of existing resources. This will require a formidable effort.

The North–South scientific gap is characterized by stark differences in:

- access to high-quality laboratory facilities, equipment, and supplies;
- the availability of well-trained teachers;
- the proportion of well-prepared and motivated students;
- links with the international scientific community; and
- access to the global stock of up-to-date knowledge.

Box 5

A Double-Edged Sword

Science and technology have a good track record in generating and applying new knowledge to improve the human condition. They can justly claim to have made a positive difference to the lives of billions. High-yielding varieties of rice, sulfa drugs, powerful antibiotics, oral contraceptives, electricity, and cheap and durable plastics are just a few examples of scientific advances that have had an enormous, direct, and positive impact on living standards across the world.

Not only is the practice of science and technology important to development, but so are its intrinsic values. These values generate, in turn, positive spillovers for the wider task of modernization and social transformation as the creativity, objectivity, and healthy skepticism about both old and new claims that are important to science find a wider application. And it is in higher education institutions that many of these values are championed. However, scientific and technological "progress" can also threaten the public interest. Nuclear missiles posed an extreme threat to world security for decades, but with the Cold War over, developing countries are now diverting scarce resources into developing their own nuclear capacity. Advances in genetics bring a host of moral and practical problems. Private industry is currently patenting new ways of producing food at an astonishing rate. Terminator genes, which are used solely for the purpose of rendering sterile new, high-yielding seeds, are one example of a technology that appears to be in the interest of industry rather than farmers. Monsanto's recent announcement that it would not pursue their commercial use was a response to both US farmers' concerns and a campaign by, and on behalf of, developing-world farmers.

But even these problems are exacerbated by a lack of indigenous science capacity in developing countries. Foreign experts can catalyze and contribute to various initiatives, but they cannot provide the sustained input that is needed to help developing countries use science as a tool for development rather than destruction.

Science and technology have, to some extent, the character of a public good—and market forces often provide less demand for scientific research than is socially desirable. National governments (both singly and in concert) must therefore act to counter this market failure. International organizations must play a vital role, recognizing the global public benefits of scientific inquiry and education. National and international organizations have the ability to finance large investments in the development and maintenance of scientific capacity—and to support long-term efforts in science when exact benefits are often difficult to predict. National and international organizations also have a duty to increase the public understanding of science, encouraging public support for the values embodied in scientific inquiry.

The Task Force recommends the following five areas for specific action:

- physical and technical resources;
- human resources;
- local, regional, and international cooperation;
- strategies for scientific development; and
- university–industry cooperation.

Physical and Technical Resources

By their very nature, science and technology have always demanded significant, ongoing investment to establish, maintain, and expand the "engine" of physical infrastructure—including laboratories, libraries, and classrooms. They also need a rich (and expensive) fuel of textbooks, computers, equipment, and other supplies. Investment in physical capital is often prohibitively expensive, with tariffs on imported goods, particularly computer hardware and software, contributing to the problem. India's formidable software industry, for example, did not develop until the removal of high tariffs on imported computers. Had these barriers fallen sooner, India might well have enjoyed the economic benefits of this rapidly growing sector much earlier. The Task Force believes it to be especially important that governments consider tariff exemptions for scientific and technical equipment imported by educational institutions.

Developing countries could also benefit to a much greater extent from the second-hand, but essentially state-of-the-art, research instrumentation that can be purchased on the world market; while the equipment is currently available, many countries are not aware of it. Donor institutions should consider establishing a not-for-profit global clearinghouse for this equipment. It would be useful not only in higher education, but also in many developing-country industries. But shortages of scientific equipment are unlikely to be totally resolved by these measures alone. Within limits, greater government initiatives either to purchase such equipment or to engage donors in providing it would be worthwhile.

The price of appropriate textbooks is also a problem. Books are often extremely expensive in developing countries, even relative to the incomes of upper-middle-class students, and, without sufficient books, the access of university teachers and students to the world stock of knowledge is limited. International agencies already buy (or subsidize) and distribute textbooks, but they should also consider alternative solutions. In many fields, it should be possible for instructors at different institutions to achieve some degree of coordination in their adoption of a relatively small set of textbooks. Such coordination narrows the range of perspectives to which students are exposed, but it allows bulk buying of books that greatly reduces costs. This policy could be combined with the relocating of production to developing countries. With regional cooperation, the production of a single Asian edition of a key textbook would be possible, for example using lower-cost local publishing houses. Successful examples of this policy already exist in other fields, for example in health, where the bulk purchase of pharmaceuticals is common. Higher education institutions should also make more extensive use of editions of books published within the past year or two, which are often available at significant discounts.

Computer-based technologies have the potential to dramatically transform higher education in developing countries, and are clearly applicable to science education. Networks and new forms of teaching media have already influenced training and research in industrial countries. They reduce intellectual isolation while providing increased (and ever-faster) access to the very latest scientific information—serving as "learning commons" (see Chapter 3). The research capabilities of the Internet, combined with basic word-processing software, can increase the ability of researchers to contribute to mainstream scientific publications. Intelligent tutoring systems and instructional software offer uniformly high-quality training on complex topics. Some of this technology is supplied in novel and flexible ways. Internet cafés are springing up in all corners of the world, providing reliable and relatively low-cost access to the Internet. Others must be provided centrally—and require substantial ongoing investment.

Another sector experiencing technology-driven change is distance learning (see Chapter 1), which will continue to grow as education reinvents itself in the digital age. However, science and technology education frequently depends on direct, hands-on experience of complex experimental techniques and technologies. As yet these are difficult to deliver via the Internet. Further, it is through a period of time spent in tertiary education institutions that almost all seriously able scientists and technicians enter the marketplace. And while corporate education initiatives continue to develop, more traditional modes of higher education will continue to have a vital role to play in skillfully developing the interest, initiative, and knowledge base of science and technology students at a critical stage in their lives.

Computers and Internet connections are available in nearly all developing countries, and access will increase sharply as computer costs continue to decline, and wireless communications systems and solar-powered electric generators proliferate in remote locations. In the meantime, many countries use outdated computers that cannot run the latest versions of many programs. Unless computer equipment can be updated frequently, both students and scientists will be frustrated in their efforts to keep pace with scientific developments in the industrial world. The pace of technological change in the industrial countries is so fast that some such frustration is almost inevitable—but for countries and institutions where computers are still extremely scarce, older computers, available at low cost, will be quite valuable. The key to this is to understand the limits of older software and hardware. Older technology is never a panacea when the pace of change is so rapid. If educational institutions can convince people (and local small businesses in particular) of the fact that older computers are often perfectly adequate for many tasks, they will be better placed to sell off such equipment in order to invest in newer models. Further, the notion of global clearing-houses for research instrumentation outlined above is equally applicable to computing technology. Similarly, the many imaginative schemes developed by several sectors to provide, for example, agricultural tools, spectacles, pharmaceuticals, and books for the developing world could also be extended to computing power.

Human Resources

Scientists working in developing countries have certainly made contributions to the world's stock of scientific knowledge and technological know-how. The contribution made by Chinese traditional medicines to healthcare has been significant, spanning from acupuncture to treatments for a form of leukemia. However, a far greater number of developing-country scientists have contributed only minimally, often from want of adequate training, facilities, supplies, access to scientific literature, and interaction with knowledgeable and imaginative colleagues.

The lack of well-qualified science and technology teachers and researchers is a widespread problem in developing countries, particularly in Africa, with its very small base of individuals who can create a science-oriented culture (although see Box 7, below).

Faculty salaries and benefits therefore need urgent attention. It is also clear that industry has a significant role to play in the area of science and technology. The knowledge society is encouraging a much closer relationship between governments, researchers, and commercial interests, with new alliances increasingly recognized. Governments are frequently directing research aims toward the good of the national economy, while industry looks for quick commercial development of academic research. Within this context, industry can play a key role in revamping incentive structures for educational institutions, imposing specific hiring standards, and establishing competitive scholarships, loans, work-study, internship, and research grant programs. Such arrangements can benefit all concerned: business, educational institutions, and students.

Brain Drain

Outstanding scientists are often peripatetic—they seek imaginative colleagues, excellent facilities and, increasingly, financial rewards. This is a problem that applies to all countries, but in developing countries, which have so few scientists, the impact of such migration can be enormous (see Box 6). Estimates indicate that about one-third of foreign students studying in the United States do not return to their home countries. Those who do return frequently bring considerable knowledge and skills back with them. There is a drawback, however, since their new expertise may well be skewed toward the research agenda of industrialized countries rather than their own.

Another, less widely noted aspect of the brain drain is known as the "camp-follower" phenomenon. Scientists and other academics in developing countries often orient their efforts toward those that are taking place in industrial countries, for example choosing topics and methods that mimic academics in other regions in order to become (or remain) part of mainstream research. When the focus abroad changes, local researchers also change their focus. The goal is often to win a temporary or permanent position abroad or to secure international funding for in-country work. The intermediate result is that, effectively, "brain drain" can take place in the absence of actual emigration.

The widespread outflow of qualified individuals stems from dissatisfaction with local conditions and inadequate scientific support—and from greater intellectual and earning opportunities abroad. Although the new information technologies may dampen scientists' and engineers' incentives to emigrate, the brain drain phenomenon is likely to continue in the absence of specific countervailing actions. The retention of top-level talent in developing countries requires improved governance in higher education institutions, greater intellectual opportunities, higher professional salaries, and better working conditions. Countries must also develop further incentives, such as academic freedom, support

Box 6

When Students Study Overseas

In many countries, both developing and developed, significant numbers of students study at overseas institutions. (The appendix to this report gives UNESCO's figures on this phenomenon.) The benefits from this practice can be substantial as students are exposed to ideas, techniques, and entire fields of study that differ from what is on offer at home. And in many instances the quality of the education they receive is better than what is available in their own country. Not only students, but countries as a whole, can benefit from such study.

Nevertheless, a country whose students go abroad for higher education faces some disturbing consequences. First, the cost of overseas instruction, particularly if it takes place in a developed country, is generally extremely high. If the student's home country pays for this education for a large number of students, this can represent a significant fiscal drain. Even if an outside donor is paying for the student's education, study abroad means that funds from donor agencies are being used to pay for a very expensive type of higher education. Such funds could, in principle, be used more effectively to promote quality higher education in the developing country itself.

Second, study abroad is often a student's first step toward resettling abroad. A country may invest large amounts of money in training students abroad only to find that they very often do not come back. Thus, even if a student's family is paying directly for the overseas education, there is a potential negative consequence for the sending country. Various schemes have been employed to encourage students to return, but in the end they have met with only partial success. It is apparent that the benefits of this accrue with donor countries, not developing countries.

The status that accompanies overseas study, along with the skills that students learn abroad, mean that this practice will undoubtedly continue to play a prominent role in providing tertiary education to a substantial number of students from developing countries. However, given the consequences of an indefinite continuation of this tradition, countries would benefit by sufficiently improving their higher education systems to attract a greater portion of their students to study in-country.

for international collaboration, and enhanced job security, in order to lure back and retain their most talented scientists and engineers. Sustained imaginative efforts to attract and host international academic and research conferences, for example, would help contribute to the cultural revaluation of science and technology. Exchange schemes, mentor programs, and other innovative approaches could be developed to attract higher caliber researchers to the country. Scholarship and loan opportunities, targeting students who prove that they will return home following studies abroad, may also be a feasible and economically appropriate way to reduce brain drain.

India is a country that has had some success in reducing brain drain. The near-universal emigration of their computer science graduates a decade ago has now declined to 70 percent. This has largely been due to the growing number of highly paid jobs with national and multinational corporations that were established following market liberalization. Growing demand for skilled graduates in fields such as software engineering, financial services, and telecommunications has also provided some impetus for improved training in these fields.

Complex relationships are at work here, with government, industry, and academia all

Box 7

African Science Moves Forward

African science recently received a boost when a particularly imaginative proposal—to explore how resources freed by debt relief can be committed to science and technology—was offered by 50 African ministers who met at the World Science Conference in Budapest. This was the largest meeting of African science ministers in more than 20 years. Cameroon's Minister of Science and Technology (and mathematician) Henri Hogbe Nlend said the conference "has given us an opportunity to relaunch inter-African cooperation in science."

The African ministers will follow the conference with another meeting, held by the Organization of African States, to discuss a pan-African scientific collaboration protocol. They hope such a protocol will be signed by heads of state. In particular, they want to explore building links between richer and poorer African countries as well as between industrialized and developing countries.

The Task Force hopes these initiatives will build on existing ones, such as The University Science, Humanities and Engineering Partnerships in Africa (USHEPiA). This is a collaborative program, launched in 1994, building on existing potential to develop a network of African researchers capable of addressing the developmental requirements of Sub-Saharan Africa. Involving universities in Botswana, Kenya, South Africa, Tanzania, Uganda, Zambia, and Zimbabwe, USHEPiA initiates fruitful educational exchanges involving masters and doctoral students, lecturers, and postdoctoral fellows. USHEPiA also promotes productive, collaborative research on problems challenging Africa.

The Task Force applauds these initiatives and hopes they will be fully developed over the coming years.

having a role to play. Fragmented effort will not suffice. Environment, tourism, and business development are all areas where governments have begun to recognize a need to think and act strategically across departmental interests. Science and technology increasingly define our future. It is therefore vital to the future of developing countries that they turn to the task of systematically nurturing—and retaining—their science and technology talent.

Women in Science and Technology

Although there has been measurable progress over the past 30 years, a global pattern whereby women are under-represented in all sectors of education persists; this pattern does mask important regional and local variations, however. The widest gap by gender is seen in South Asia, the Middle East and Sub-Saharan Africa, but women are increasingly well represented in Latin America.[8] The gender imbalance is particularly strong in the areas of mathematics, the physical sciences, and engineering, but in many developing countries, this imbalance is notably smaller in the medical sciences. Women are also disproportionately enrolled in alternative forms of higher education, such as distance education, teacher training colleges, nursing schools, and nonuniversity, tertiary-level institutions. There are also clearly social pressures on women to pursue traditionally "female" subjects in the

[8] World Bank, *World Development Indicators 1997*, p. 73.

humanities, education, and nursing at the expense of science and technology disciplines.

As noted, this problem is by no means confined to developing countries. Approximately 2 percent of the people on the United Kingdom Engineering Council database, for example, are female. There are also many social constraints to female participation in higher education in general, with higher education perceived as a predominantly male environment. The lack of female participation in mainstream higher education and science and technology disciplines means that many countries currently realize only a portion of their potential in these areas.

Developing countries should therefore urgently explore ways to promote the participation of women in the sciences. The international development community has come to recognize the great social benefits of educating girls at the primary and secondary levels. Now it must recognize the value of educating women at the tertiary level, including in scientific fields. Once initiated, the process will gain momentum as successful female professionals—including scientists—provide positive role models. A positive result would be a narrowing of the gender gap in science and technology and a simultaneous enhancing of national scientific achievement. In addition, since professional women tend to be less internationally mobile than men, increasing the share of investment in science education directed toward women will presumably help to reduce brain drain.

Because of numerous social and cultural barriers, including falling behind their male peers when they have children, special measures may be required to help women achieve leadership roles in science. Mentoring programs for women in mathematics and science have had a positive effect on retention rates. Increasing scholarship assistance and loans to women would undoubtedly help. Actively recruiting women for graduate study and developing supportive networks (see Box 8) would also help promote a culture of female participation in science and technology.

Box 8

Gender Agenda

Women's role in science has come under increased scrutiny of late, and this was formalized when the final documentation emerging from the World Science Conference in Budapest systematically acknowledged gender issues. Sjamsiah Achmad of the Indonesian Institute of Technology in Jakarta, who chaired the gender issues session, noted "it's the first time the issue has entered the world science agenda."

Another Indonesian delegate, Wati Hermawati, welcomed the call to develop gender indicators. She will work at the National Focal Point for Gender, Science and Technology (part of Achmad's Institute) to develop gender indicators on, for example, participation, education, and career structures. "Until now we've had no indicators," she pointed out. OECD (Organization for Economic Cooperation and Development) members have carried out comparative studies of scientific efforts, but hitherto have not collected gender data. Meanwhile, UNESCO recently announced its intention to fund a science and technology network for Arab women. Another group is currently negotiating a support network in Jakarta to serve the Indonesian and Pacific region.

Improving Primary and Secondary Preparation

Recent international evidence reveals considerable cross-country variation in mathematics and scientific achievement at primary and secondary levels, both among developing and industrial countries.[9] Science and mathematics are both "building block" subjects in that progress is particularly reliant on what has already been learned. Country authorities therefore need to improve primary and secondary institutions' curriculum development, teachers' qualifications, teaching techniques, and access to key inputs such as textbooks, laboratory facilities, and information technology. Further, systematic attention at the primary and secondary levels to many of the cultural issues regarding gender would also facilitate an enhanced flow of women's participation.

Local, Regional, and International Cooperation

Higher education institutions benefit greatly from connections with similar institutions. For scientists in the developing world, the paucity of such contacts is often an impediment to their creativity and productivity. They lack a direct pipeline into current scientific awareness, lack opportunities for mainstream publication, and are part of few professional partnerships or networks. (Few things are more disconcerting to researchers than to be informed that their new "discoveries" were already known to others.) Unlike colleagues in the humanities or social sciences, much of their subject matter is almost totally incomprehensible to the wider population and it is thus even more important that developing-world scientists be able to plug into those sources of support and inspiration that do exist.

Ways of overcoming isolation include organizing conferences, providing travel grants allowing researchers to reach more distant venues, and ensuring access to telephones and computer-mediated communication. All of these actions would help promote interaction among a corps of geographically dispersed scientists. Links could also be promoted, for example, by the formation of an international volunteer corps of scientists (some of whom might be retired) who could offer their services by teaching or consulting in specific fields or on particular projects. Such pro bono cooperation, for which successful examples exist in fields such as financial service, has to be handled with care (for example, would-be helpers sometimes arrive unprepared), but the potential benefits are enormous. The Financial Services Volunteer Corps draws on working professionals in the banking and corporate sector and since 1990 has sent over 1,000 volunteers to former communist countries. They have completed over US$100 million worth of pro bono work, in countries as diverse as Russia, Hungary, and Moldova (see www.fsvc.org).

Cooperation is especially important at the regional level, helping individual countries to achieve a critical mass in scientific subjects. Fellowship programs to train energy analysts in developing countries have been established in prestigious universities in several countries in Asia, Africa, and Latin America, for example. The University Science, Humanities and Engineering Partnerships in Africa (USHEPiA) is also doing groundbreaking work in Africa (see Box 7).

International networks, meanwhile, provide promising opportunities for promoting

[9] This is well documented in the Third International Math and Science Study (TIMSS) by the US Department of Education. Please read *Pursuing Excellence: A Study of US Twelfth-Grade Mathematics and Science Achievement in International Context*. More information can be found on the following websites: www.nces.ed.gov/timss/twelfth/ or www.ed.gov/inits/timss or www.nces.ed.gov/timss-r/.

scientific innovation appropriate to the needs of developing countries. The Consultative Group on International Agricultural Research (CGIAR) is an example of a global program of research on agricultural issues having direct relevance to developing countries, such as rice production, food policy, agroforestry, and irrigation. The World Bank and three other United Nations agencies established the CGIAR in 1971. The network owes its existence and continuation to the financial support of multilateral donors, amounting to some US$300 million per year. Many of its achievements, ranging from the development of new rice varieties that sparked the Green Revolution to appropriate methods of soil and water conservation, represent international public goods that are unlikely to have evolved without concerted action.

International research centers such as those in the CGIAR network are sometimes criticized for failing to build scientific capacity within their host countries. The Task Force does not believe this is a valid observation. CGIAR centers, for example, have helped train more than 50,000 scientists in developing countries. But we believe more can be done to ensure that any investment in scientific capacity reinforces, rather than competes with, ongoing national efforts—an approach that will be further enhanced as national responses become more focused and coordinated. Local counterpart institutions, working in conjunction with internationally funded centers, can greatly enhance the value of international networks. Such cooperation gives local institutions an entree into the global research world and greatly spurs local efforts.

The Indian Institutes of Technology provide one example of beneficial crossovers from the international to a national science community. Five institutes were established in the early 1950s as "institutions of national importance," modeled explicitly after the best examples of technical higher education from Germany, Russia, the United Kingdom, and the United States. Throughout the 1960s each of the institutes was heavily funded by a different country, and staffed by top-ranking faculty from both India and the funding country. Today the Indian Institutes of Technology enjoy not only national, but also international, prominence in several technical fields, operating successfully as Indian rather than as international institutions.

Reform of the International Intellectual Property Rights Regime

As more countries participate in the global economy, protection for the results of investment in knowledge creation has become increasingly important. Currently, however, most patents protect advances made in industrial countries, and licensing fees for product development based on new inventions are often prohibitively high. Universities and research institutes in developing countries therefore face significant financial barriers to research and, in the future, whole regions may find themselves cut off from participation in the global network of innovators.

Although this problem is not yet serious, there is growing recognition that it is likely to become so as the international intellectual property regime becomes more formalized. (The World Science Conference in Budapest, for example, was dominated by intellectual property issues.) Wider use of a sliding scale for licensing agreements, taking into account a country's level of development, would be helpful. Alternatively, these countries could purchase, perhaps with a subsidy from an international organization, a countrywide site license for access to software and particular research techniques. Another possibility would be to promote North–South joint ventures in which developed- and developing-country participants earn and share intellectual property rights. Advances in this area will need to be carefully thought through from the point of view of both the developing country and the intellectual property holder. Arrangements that do not give the property holder clear protection regarding the resale of technology are unlikely to be sustainable.

In this area, in particular, developing countries need to adopt emerging best practices from the industrialized world. The United Kingdom's National Endowment for Science, Technology and the Arts (NESTA),[10] for example, has explicitly committed itself to exploring creative partnerships with innovators where, in exchange for bearing some of the risk and providing financial support, NESTA obtains a percentage of the intellectual property rights. Profits are fed back into the funding loop. Where models do not exist, however, developing countries should be prepared to innovate. The knowledge economy will demand new and quite different institutions—and these may come more quickly in emergent than in mature economies.

Strategies for Scientific Development

The capacity to carry out scientific research is extremely limited in many developing countries. While not every country needs to conduct basic research in every field, each country must consider the types of scientific and technological research that can directly contribute to its development. In view of the costs and other difficulties, perhaps the right question to ask is: what is the *minimum* level of scientific and technological capacity necessary to achieve national goals?

At the very least, every country needs to be able to turn to a small corps of its own citizens for informed guidance and expert advice about scientific and technological developments. In addition to people who can choose wisely among technologies, there is a need to support and promote people who can begin to build scientific self-reliance. International collaboration is important in achieving this—with regional cooperation essential for those smaller countries in which a research university is not practical (see Box 2, Chapter 1). Selective excellence is also an important strategy, where countries focus on building strength in a few selected scientific disciplines—which should correspond closely with a country's needs and its comparative research advantage. For example, a country with a long coastline might naturally gravitate toward marine biology, while countries subject to volcanic eruptions and earthquakes would want experts in soil mechanics and construction engineers skilled in designing earthquake-resistant structures.

On a global level, market forces are a crucial determinant of the allocation of scientific effort among competing substantive issues. AIDS and malaria each claim roughly as many lives a year, but AIDS is far more prevalent in richer countries than malaria, and receives far more research funding. The lack of effective demand also explains the paucity of research in other areas that have great potential for improving the living standards of the world's poor. Examples include research into chimney and other ventilation systems that would protect household members (mainly women and young children) from respiratory ailments and eye problems caused by indoor pollution; and the development of nonsterile varieties of hybrid corn and of wheat, rice, and corn varieties that can better fix nitrogen in the soil and thereby reduce the use of chemical fertilizers.

Achieving a tighter focus on national, regional, and even global research priorities will inevitably involve multiple sets of stakehold-

[10] http://www.nesta.org

ers. While the World Health Organization has a global role, so too does the wider international donor community—who usually have access to substantial high-quality science and technology expertise and resources. The more coordinated response recently outlined by African science ministers (see Box 7) also offers a greatly extended opportunity to focus efforts, as do initiatives such as those of the William H. and Melinda Gates Foundation, which recently donated US$50 million for work on a malaria vaccine. National governments, too, can play a role. For example, the science and technology community in the United Kingdom has seen a shift, in barely a decade, from a research agenda entirely defined by scientists and researchers to one driven more by the outputs that the government, as the client, wants to buy.

Scientists and researchers themselves can also help drive the research agenda on global priorities. This century has seen many examples of moral leadership by scientists, most recently from Nobel prizewinner Joseph Rotblat of Pugwash (who recently argued that scientists should take the equivalent of a Hippocratic oath). Within higher education institutions—especially research universities—scientists have a great deal of academic freedom and insulation from commercial pressures. Scientists from all countries have a responsibility to use this privilege, which is heavily funded by society, for society's good. The work of scientists constantly challenges us, with its potential to benefit humanity, or to harm it. Nuclear technology can be simultaneously seen as a curse or a blessing, offering a formidable weapon but also a treatment for cancer and a source of plentiful electricity. The work of scientists in the field of genetics holds before us the opportunity to tackle age-old diseases, while it also augurs the specter of genetic selection. Each advance gives humanity choices that require a special responsibility from scientists.

Finally there is the public. There is a strong case for extensive and effective public communication about science, thereby enhancing cultural support for science and technology, and about its content—for example, safer sex campaigns based on scientific understanding of sexually transmitted diseases such as HIV. Public involvement in science must go further than this. If science is in part a public good that needs to be at least partly publicly funded, then the public has a clear interest in scientific objectives, processes, and outcomes. Strategies to support scientific development will need to encourage the creation of an open and accountable scientific community and recognize the importance of public support for continued scientific development.

University–Industry Cooperation

Developing countries have a great potential for strengthening science and technology links between higher education institutions and industry. Universities are predominantly nonproprietary settings and, because they bring together representatives of all disciplines into a single place, they provide fertile grounds for cross-pollination. Commercial, specialized research centers also produce top-notch research, but their capacity is sometimes limited by the narrowness of their focus. The development of new technologies consists of three types of interconnected activities: (i) research, (ii) technology development and adaptation, and (iii) production and marketing. The largest role for universities is in carrying out the initial research, but subsequent product development and distribution often result in a fruitful interplay between universities and industry. In many developed countries an increasing number of companies are spinning off from universities, a process that happens when researchers are encouraged to look for commercial applications of their work. Because some technical expertise can be acquired only through learning-by-doing, industrial apprenticeships are also an effective means of training new cadres of highly skilled workers. In fact, the very nature of the knowledge revolution, and the intimate links between, for example, academia and the Internet or biotechnology, have helped shape a different set of cultural values around such collaboration. Where industry's relationship with universities was once based on geographical links or the interests of alumni, today's collaborators are seeing a "death of distance" as technology enables collaborations to work at huge distances. This culture can, in due course, extend benefits to developing countries.

Many countries—Argentina, Brazil, Chile, China, Colombia, the Arab Republic of Egypt, India, Kenya, Malaysia, and Nigeria, among others—have taken active steps to forge stronger links between their academic and industrial sectors. In Brazil, this interaction resulted in the development of an alternative fuel that replaced half the country's use of gasoline automobiles with renewable, domestic sources of energy. As another example, high rates of maternal mortality in rural areas in India caused by lack of access to blood transfusions inspired the development, in one medical research center, of low-cost plastics that could resist the inherent corrosiveness of blood and be used for storing blood. The international marketing of this product has been handled in a completely commercial manner, with some of the proceeds being used to subsidize local use of the product.

Conclusions

The problem of insufficient scientific capacity in developing countries is acute, but it is not insurmountable. Higher education has played a leading role in bringing about impressive scientific achievements under difficult circumstances in various parts of the developing world. Generally, these achievements have arisen as a result of an early, deep, and sustained commitment to particular areas of science or technology.

Notwithstanding the success stories, developing countries are falling further behind industrial countries in terms of their science and technology capacities and achievements. Perhaps the most disturbing aspect of this trend is that many areas of scientific inquiry that hold great promise for the development of international public goods are receiving inadequate attention. These problems bode ill for social and economic development, and suggest a further widening of global inequality in standards of living. Many very useful discoveries end up sidelined because of a lack of support either from business or government, not because they are inherently inapplicable. In the case of the Baylis wind-up radio that requires neither outside sources of electricity nor batteries—a very popular product manufactured in South Africa that has brought news and information to many poor families—the inventor spent long, frustrating years trying to raise the interest of manufacturers. This useful invention would still remain unknown were it not for some seed money from the British government.

Inadequate resources (both physical and human) for science education, and the absence of key values and traditions that promote effective scientific inquiry and training, are among the main causes of the deteriorating position of developing countries in the sciences. We have suggested some means by which higher education institutions and governments can address these problems. Strong international leadership that provides sustained intellectual and financial support for strengthening the scientific capacity of developing countries is also urgently needed. Equally important are efforts to strengthen scientific links between institutions of higher education in developing countries and centers of scientific excellence worldwide.

The key question that will exercise policymakers in developing countries is "where should promoting science and technology higher education rank in the long list of priorities for resources?" The answer will vary from country to country. Science and technology are moving with extraordinary speed. Countries such as India and many of the Southeast Asian economies now play a strong role in the development of software and hardware. With the many incalculable spin-off benefits yielded by technologies such as the Internet, the world is entering the future before our eyes. Playing a role in that future requires every developing country to think strategically about how their inevitably limited resources for science and technology higher education might best be deployed to the advantage of future generations.