STRATEGIC APPROACHES TO SCIENCE AND TECHNOLOGY IN DEVELOPMENT

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FINAL DISCUSSION DRAFT

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This paper on Strategic Approaches to Science and Technology in Development was produced along with a companion second volume, entitled "A Resource Book for S&T in Development." This second volume treats many of the issues discussed in this strategic approaches paper in greater detail, and contains background research used in the production of both volumes. Throughout this paper, footnotes will direct the interested reader to the more detailed discussions contained in Volume Two. Full citations for publications cited in both this strategic approaches paper and the Resource Book may be found in the annotated bibliography included in the Resource Book. The following page presents the Table of Contents for Volume Two.

Table of Contents for Companion Volume Two

"A Resource Book for S&T in Development"
(Available in hard copy)

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Annex 1	**Regional Issues in S&T Policies for Developing Countries…………………….**
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List of Acronyms

CGIAR	Consultative Group on International Agricultural Research
DALY	Disability-Adjusted Life Years
DANIDA	Danish Ministry of Foreign Affairs
DGF	Development Grant Facility
DGIS	Dutch Ministry of Foreign Affairs
ENRECA	Enhancing Research Capacity (Research Program of DANIDA)
ERC	Engineering Research Centers
ESSD	Environmentally and Socially Sustainable Development
FDI	Foreign Direct Investment
FY	Fiscal Year
GDP	Gross Domestic Product
GM	Genetically Modified
GTOE	Thousand Million Tons of Oil Equivalent
HDN	Human Development Network
IARC	International Agricultural Research Centers
ICSU	International Council for Scientific Unions
ICT	Information Communications Technology
IFS	International Foundation for Science
InfoDEV	Information for Development Program
IPCC	Intergovernmental Panel on Climate Change
IPR	Intellectual Property Rights
ISR	Industry-Science Relations
ITD	Industrial Technology Development
JICA	Japan International Cooperation Agency
MDG	Millennium Development Goals
MFP	Multi-Factor Productivity
MSB	Mauritius Standards Bureau
MSI	Millennium Science Initiative
MSTQ	Metrology, Standards, Testing and Quality
NARIS	National Agricultural Research Institutes
NARS	National Agricultural Research System
NGO	Non-governmental Organization
NIS	National Innovation System
NORAD	Norwegian Agency for Development Cooperation
ODA	Official Development Assistance
OECD	Organization for Economic Cooperation and Development
OED	Operations Evaluation Department
PISA	Program for International Student Assessment
R&D	Research and Development
S&T	Science and technology
SAREC	Department for Research Cooperation of SIDA
SIDA	The Swedish International Development Cooperation Agency
SME	Small and Medium Enterprises
SPAAR	Special Program for African Agricultural Research
TDS	Technology Diffusion Scheme
TIMSS	Trends International Mathematics and Science Study
TSC	Technology Strategy for Competitiveness
TWAS	Third World Academy of Sciences
UNAIDS	Joint United Nations Program on HIV/AIDS
WBI	World Bank Institute

STRATEGIC APPROACHES TO S&T IN DEVELOPMENT: EXECUTIVE SUMMARY

Since its founding, the World Bank has sought to promote specific aspects of science and technology (S&T), especially in the area of agricultural research. This Strategic Approaches Paper underscores the ways in which science and technology support poverty alleviation and economic development, and explores the room for improving the effectiveness of the Bank's role in this area. It will serve as an input into various formal sector strategies in which S&T issues bear on the achievement of the Millennium Development Goals and the pursuit of the World Bank's Corporate Advocacy Priorities, as well as on the creation of a climate for investment, jobs, sustainable growth and the empowerment of poor people. The paper argues that development will increasingly depend on a country's ability to understand, interpret, select, adapt, use, transmit, diffuse, produce and commercialize scientific and technological knowledge in ways appropriate to its ambitions and level of development.

The paper analyzes the importance of S&T for development, presents policy options for enhancing the effectiveness of S&T systems in developing countries, reviews the previous experience of the World Bank and other donors in supporting S&T, and suggests ways that the World Bank can increase its effectiveness through better integration of the work currently undertaken in S&T. Its main messages are that: (i) S&T has always been important for development, but the unprecedented pace of advancement of scientific knowledge is rapidly creating new opportunities for and threats to development; (ii) most developing countries are largely unprepared to deal with the changes that S&T advancement will bring; (iii) the World Bank's numerous actions in various domains of S&T could be more effective in producing the needed capacity improvements in client countries; and (iv) the World Bank could have a greater impact if it paid increased attention to S&T both within strategies in particular sectors and by achieving synergies among on-going S&T-related lending and grant activities in, *inter alia*, the Education, Health, Rural, Private Sector Development, and Environment sectors.

The role of S&T in sustainable development is receiving vigorous attention in the context of the World Summit on Sustainable Development. The major international S&T organizations are updating their strategies to reflect the renewed emphasis on S&T that sustainable development requires. The United Nations, in particular, has identified five areas (Water, Energy, Health, Agriculture, and Biodiversity) as particularly critical for progress. The World Bank should be ready to play an appropriate role along with partner agencies in this new environment of S&T prioritization.

The Importance of S&T for Development. Science and technology have been central in the progress made to date in the fight against poverty and in stimulating economic growth. Today, however, the accelerating rate of progress in science and technology creates both tremendous opportunities and significant risks for developing countries. A lack of capacity among some developing countries to even access and utilize advances in S&T has prevented them from capturing the benefits of S&T that have become commonplace in the rest of the world. To date, the cost to developing countries of low S&T capacity has been confined mostly to lost opportunities, such as in the failure to capture the benefits of the Green Revolution in Sub-Saharan Africa. In the future, active threats to, *inter alia*, food safety, natural capital, and human health will join lost opportunities in comprising the full costs of inadequate S&T capacity. More specifically:

- In **agriculture**, advances in S&T have facilitated higher yields, greater efficiency, and greater nutritional content in the world's food supply. Food production, however, must double in the coming decades to meet rising demand, and meet the challenges entailed in, *inter alia*, improving resistance to drought, pests, salinity and temperature extremes; raising the nutritional content; and reducing post-harvest loss all in an environmentally and socially sustainable manner. At the same time, the regulatory challenges of assuring safety in food production and consumption will increase exponentially.

- In **health**, advances in scientific knowledge and its application have helped slow the trend of "high fertility, high mortality" and led to increasingly better health for many people in developing countries. Nonetheless, vector and water borne disease, AIDS, inadequate pre-natal and maternal/child healthcare and other deficiencies continue to create a tremendous burden in the developing countries. Countries will be unable to correctly identify public health needs and choose cost-effective packages of health services if they lack S&T capacity.
- Other problems, such as the needs of the 1.3 billion people who live without access to adequate fresh **water,** or whose health and livelihoods are endangered by **environmental degradation** call for development of new technologies (along with appropriate policy frameworks) to mitigate these problems and their effects on poor people. Timely local adoption often requires significant indigenous technological capacity.
- Access to affordable **energy** is essential for the two billion people currently living without electricity and is a pre-requisite for economic growth. Further advancement and application of research is needed to find new, environmentally and socially sustainable technologies that can meet the energy needs of developing countries.
- With respect to **economic growth**, emerging evidence shows that—when an enabling environment for investment is present—the developing countries that are home to half the world's poor (Brazil, China, India, Thailand, Mexico, Malaysia and the Philippines) are using technological capabilities to capture growing percentages of expanding global high tech export markets, and thereby adding to their rates of GDP growth. Other developing countries will need improved S&T capacity if they are also to capitalize on opportunities for economic growth.

Science and technology in **education** pervade all of the above themes, with existing human capacity, training, research and application composing a significant part of the paradigm for the successful use of knowledge in any domain.

Policy Options for Reaping the Benefits from S&T. Some middle-income countries have managed to create pockets of S&T capacity that at least partially serve their economic and social ambitions. The vast majority of developing countries, however, have severe deficits of S&T capacity. Improvement depends on the adoption of appropriate policies and activities in at least four areas: human resources development, demand for knowledge in the private sector, public support of S&T, and access to information and communication technologies (ICT).

- Policies for S&T in **human resources development** aim to provide science education at the basic, secondary and tertiary levels, prepare young people to enter a diverse labor force that requires various levels of S&T sophistication, and encourage the conduct of research and advanced training.
- "Implicit" policies for S&T create an enabling environment that stimulates **demand for knowledge in the private sector** through, *inter alia*, a stable macroeconomic environment, appropriate climates for trade and investment, credit policies, and an adequate intellectual property rights regime. "Explicit" policies for S&T in the private sector aim to further break down barriers to the use of knowledge. These policies may include support for firm-based training to encourage technology deepening, increase industry-academia linkages and public-

private partnerships, establish protection for indigenous knowledge, provide tax incentives for firms engaged in R&D, and stimulate "clusters" of knowledge-based industries.

- Policies for **public support of S&T** must address the various aspects of the public role in the national innovation system, including: setting priorities for funding and research, providing financing, instituting open, transparent peer-review selection processes, establishing governance, regulatory and management mechanisms, incorporating the results of research into public policy decisions, and monitoring and evaluating the system.
- Policies for **information and communication technologies** should seek to maximize the access to and flow of knowledge by, *inter alia*, extending access of available ICT to a wider range of users, improving the regulatory framework to facilitate a conducive environment for ICT growth, and providing training and education to facilitate broader use of ICT.

Lessons From Previous Experience in S&T Capacity Building of the World Bank and Other Donors. Annual World Bank lending for S&T is roughly $500 million per year, about half of which is in the Rural/Agriculture sector. Most non-agriculture lending is to a small number of middle-income countries in East Asia and Latin America. Another $100 million in grants is provided to S&T-related activities through the Development Grants Facility. Total donor and foundation contributions are harder to quantify, but are estimated at roughly the same order of magnitude. The main findings from previous experience are that: (i) with the exception of Agriculture/Rural Development, no sector has given systematic attention to or pursued a coherent strategy to promote the appropriate role of S&T for development, despite its recognized importance; and (ii) promoting S&T requires a sustained, coordinated multi-sectoral approach that has not yet emerged from the myriad of different activities that the World Bank has sponsored. Recently, more sectors appear to be recognizing the need for greater integration, but the progress made toward this goal has been modest and has come slowly.

In particular, lessons such as those highlighted below have shown that effective policies for improving S&T capacity in developing countries vary by country size, population, level of development, previous traditions, existing capacity, and factor endowments. Smaller and poorer countries face a special set of challenges.

- **Human resources development**: Historically, the World Bank has not always emphasized science at the basic and secondary levels or the assessment of student learning outcomes. The support given has focused to a great extent on the provision of physical inputs at the expense of teacher training and curriculum development. The World Bank has been more successful with S&T at the tertiary level in middle-income countries when investments have been made over a period of a decade or more.
- **Stimulating demand for knowledge in the productive sector**: Success in building technology capacity has been greatest when it has been linked to an explicit national science and technology strategy. In contrast, the disconnect of the productive sector from research and development was identified by OED as a factor limiting the success of technology development efforts. This is as true for goods and services with "public purposes" (e.g., health care, agricultural industries, etc.) as for other industries.
- **Public support of S&T**: Effective projects were often those that helped institute open, transparent governance and peer review systems, linked research more closely to graduate training and higher education policy more generally, and ensured greater relevance of research. At the same time, a host of particular investments made through the DGF (including, but not limited to support for the CGIAR) show that targeted investments in research can yield high impact economic and social results. More recently, the World Bank has piloted support to improve research excellence through the adoption of international best

practice funding mechanisms (e.g., competitive, peer reviewed selection, intensive human resources training, and investigator autonomy coupled with adequate research budgets) through the Millennium Science Initiative (MSI). The MSI can be successful if implemented flexibly and carefully, integrating it with the needs of a country's education system and its development priorities.

- **World Bank experience in ICT**: As the World Bank's ICT strategy paper establishes, investments in ICT infrastructure alone are not sufficient to create ICT capacity in developing countries: concomitant investments in human capital training and strengthening of regulatory frameworks are also necessary.

Analysis of bilateral, foundation, and NGO S&T capacity building initiatives reveals that significant positive results are achievable with small, targeted budgets aimed at specific S&T-related challenges, particularly when the projects address all aspects of the challenge from the need for training to the necessity for linkages to the public and private sectors.

Rethinking the World Bank's Approach to S&T and Development. The World Bank's potential impact in promoting S&T capacity depends primarily on client interest and commitment. In addition, the degree of ownership of the issue within and across the World Bank's own Networks and Regions determines how timely and effectively we can anticipate and respond to client needs. Again with the exception of Agriculture/Rural Development, the World Bank's work on S&T has most often been the result of interest from individual staff, teams or sectors. Going forward, active synergies will be achieved by the relocation of Science and Technology to the Human Development Network as of July 2002 to more effectively promote linkages with the Higher Education group. Additionally, a possible first step toward increased focus and ownership within the World Bank is to establish an internal S&T Thematic Group with representation from the Education, Rural, Health, Private Sector Development, Energy, and Environment Departments, plus the CGIAR and the DGF. The S&T Thematic Group would consist of "champions" for S&T from these sectors, who would coordinate, share knowledge, and identify opportunities for action. These opportunities would be linked to client demand, interest and commitment; would take into consideration the World Bank's comparative advantage in the specific area and country; and would be realized within the context of the World Bank's Country Assistance Strategy (CAS).

An improved World Bank approach to S&T could, in principle, aim toward achieving the following goals:

- To **increase awareness** of S&T and its role in development: The World Bank could foster communities of practice within the organization itself so that sectoral and cross-sectoral S&T issues can be addressed productively among the staff working on these issues and with the client countries. At the same time, the World Bank's comparative advantage in dealing with global public goods priorities and cross-sectoral S&T issues would be leveraged internally as well as externally under the auspices of the WBI's outreach capabilities.
- To **increase attention to S&T in four key policy domains** (human resource development, promoting private sector demand, public sector support to S&T, and ICT): Among the many actions that can be recommended in these areas, the World Bank might increase the emphasis on science education in basic and secondary education lending, include S&T as part of the renewed and expanded emphasis on tertiary education, place emphasis on the creation of linkages between firms and knowledge institutions, reform enabling environments for better

use of knowledge, help governments with their multiple roles pertaining to S&T, and promote access to and use of ICTs.

- To **achieve greater integration** of on-going S&T support: The World Bank could build on current "knowledge assessments" and pilot coordinated lending efforts across S&T-related sectors (Education, Private Sector Development, Rural Development, Health, etc.) and promote other synergies among the S&T-related initiatives.
- To **increase and strengthen S&T-related analytical work**: The World Bank could provide analysis and policy recommendations on global public goods priorities such as brain drain, food security and new agricultural technology, and effective S&T education in developing country settings. The World Bank would also expand its participation in international scientific assessments (such as the IPCC and the Millennium Ecosystem Assessment) that have global public goods characteristics and produce policy-relevant knowledge on critical development issues.
- To **foster collaboration with a range of international partners**: The World Bank would support and build upon the successful S&T capacity building initiatives of various bilaterals NGOs and foundations, and increase professional contacts with representatives of the international science and technology policy community, including the OECD, UNESCO, the Third World Academy of Sciences, the Inter-Academy Council, the International Council for Scientific Unions, as well as national academies, science foundations, and especially experienced private sector partners and technology development specialists.

The ultimate aim of these actions would be to help the World Bank respond to the growing requests from clients, and to facilitate the appropriate attention to S&T issues within Country Assistance Strategies that will lead to improved ability to use scientific and technological knowledge for the growing list of development challenges that require it.

STRATEGIC APPROACHES TO S&T IN DEVELOPMENT

Science and Technology (S&T) are critical inputs for poverty alleviation and economic development. Advances in scientific and technological knowledge made possible the significant reductions of poverty and improvements in the quality of life in both developed and developing countries throughout the 20th century. In the future, the ability of countries to access, comprehend, select, adapt, and use scientific and technological knowledge will increasingly be the determinant of material well-being and quality of life. As a development institution, the World Bank[1] can play an important role in helping its clients use science and technology for development.

Concern for the scientific and technological capacity of its clients has been a part of the World Bank's work since its founding, but attempts to raise S&T capacity among clients has not always been sustained and systematic. Many worthwhile (but disparate) World Bank initiatives, both in lending operations and through the Development Grants Facility, have focused on an array of S&T-related issues (e.g., agricultural productivity, disease control, technical education, etc.), but these have never constituted a vision or a plan for improving S&T capacity across the board. With the acknowledgement of the importance of knowledge for development, there is room for rethinking this approach. Four of the World Bank's five Global Public Goods Priorities are strongly linked to S&T (Communicable Diseases, Environmental Commons, Information and Knowledge, and Trade and Integration). Likewise, most of the Millennium Development Goals have a strong S&T-component, and improved in-country S&T capacity is directly required to reach, sustain, and monitor 24 of the 48 MDG Indicators [See Appendix 1]. In addition, all the priority areas identified by UN Secretary General Kofi Annan (Water, Energy, Health, Agriculture, and Biodiversity) for the World Summit on Sustainable Development require advances in S&T.

Deriving benefits from science and technology depends on a number of factors including: (i) the level of education and training of the population; (ii) the demand for knowledge by the private sector; (iii) public policies that provide the appropriate enabling environment for strong knowledge institutions; and, (iv) the level and quality of the information and communication technologies systems that permit the flow and dissemination of knowledge and information. When these factors and the institutions responsible for them work together smoothly, significant progress can be made in responding to problems associated with poverty and stimulating economic growth. When the appropriate S&T infrastructure is not developed, countries fall further behind, rendered stagnant by problems that other more technologically-advanced countries have long since overcome.

This paper seeks to underscore the importance of science and technology for development, the policies that can maximize the benefits of S&T at the country level, and the strategic approaches that the World Bank and its partners can adopt to help

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[1] The paper deals primarily with the World Bank. Important future work will incorporate full consideration of the roles of all members of the World Bank Group.

accelerate the growth of scientific and technological capacity in the developing world. It proposes specific ways for the World Bank to integrate the isolated activities it currently undertakes in support of improved S&T capacity, making future actions more targeted and effective.

The paper has three sections following this introduction. Section A covers the importance of S&T for development. Section B discusses the policy options for reaping the benefits of S&T. Section C presents lessons learned and their implications for a renewed role for the World Bank regarding S&T.

It is cheaper and easier now than ever before to gain access to scientific and technological knowledge, thanks mostly to new information and communication technologies. But access to knowledge without the capacity to use it is worthless. Countries lacking adequate infrastructure to capture and use the increasing amount of accessible knowledge and information stand no chance to benefit from it. The needed infrastructure is a mix of human capacity, hardware, institutions, incentives, policies and investments. Finding ways to create and strengthen the infrastructure where it is absent is not simple, but the costs of inaction make it an imperative task.

The differences in capacity between the scientifically-advanced countries of the OECD and the poorer countries of the developing world are stark. OECD countries spend more annually on R&D than the value of total economic output of 61 of the world's lowest-income countries[2] (US$ 500 billion versus US$ 464 billion in 1998).[3] Again, compared with low-income countries, OECD countries have twelve times the per capita number of scientists and engineers working in R&D and publish 25 times more scientific journal articles per capita. In the OECD, the ratio of patents filed by non-residents to those filed by residents is 3.3 to one, while in low income countries it is 690 to one.[4] Of course, quantitative measures such as the size of R&D budgets give only a partial glimpse of the situation; they fall short of describing the full range of differences in S&T capacity. S&T capacity is a multi-faceted ensemble of human, physical, organizational, institutional, and financial capital which defies reduction to a single set of indicators.

As we would expect, developing countries are not alike in S&T capacity. Brazil, China, and India may have more in common in S&T-relevant sectors with OECD countries than with low-income countries. No single set of policy prescriptions for improving S&T infrastructure within developing countries could cover such a wide range

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[2] The low-income countries, excluding China and India: Data from World Bank's World Development Indicators 2000.

[3] OECD Science, Technology, and Industry Outlook 2000.

[4] Inventors must patent their inventions separately in each country in which they wish to have them protected. A single invention may therefore be patented in several dozen countries. Because of this, a high ratio of foreign to local patent applications indicates a low level of innovative activity among national researchers. Despite the other various factors that bear on the decision whether and where to seek patents, the ratio of foreign to domestic applications is considered a reasonably reliable indicator of national innovation effort.

of circumstances. For the purposes of this paper developing countries will be subdivided into three categories of S&T capacity:

- *Scientifically proficient countries* increasingly define their relations with the scientifically[5] advanced countries on the basis of equality or near equality; examples include Brazil, China, India, Hungary, and South Africa.
- *Scientifically developing countries* have pockets of adequate scientific and technological capacity amidst general scarcity; examples include countries such as Turkey, Colombia, Indonesia, Pakistan, and Latvia.
- *Scientifically lagging countries* lack capacity almost entirely; examples include countries such as Nepal, Albania, Mali, Ecuador, and Libya.

Depending upon where a country is situated within these three categories, the goals of S&T policy will vary across a continuum of policy characteristics as briefly highlighted in Table 1. To the extent practical, the paper's recommendations will be tailored to the different needs of these three groups,[6] with differences between country groups and their implications for policy being discussed in greater detail in the Policy Matrix in Appendix 2. However, it should be noted that there are likely to be significant differences between countries within the same overall category with respect to the four policy areas (human resources, demand from the private sector for S&T, public management of S&T, and the availability of ICT infrastructure). These differences will need to be reflected in the individual Country Assistance Strategies.

Table 1: Policy Characteristics Contributing to S&T Capacity

Scientifically-Advanced Countries	Continuum of Policy Characteristics for S&T Capacity	Scientifically-Weak Countries
Common	Functional education systems that promote sound science education at all levels	Uncommon
Common	Competitive markets that allow for the emergence of innovative firms that demand knowledge; Financial infrastructure to support innovative firms	Uncommon
Strong	Public management of S&T includes competitive, merit-based allocation of funding to basic research priorities and evaluation and accountability mechanisms for research(er) output and effectiveness	Weak
Strong, Common	Associations and networks that share information locally, nationally, regionally, and internationally across and within sectors	Weak, Uncommon

People tend to associate science and technology with the creation of new knowledge, through "frontier" or "cutting edge" research. Although this image has a strong hold on the popular imagination, it feeds a partial and biased view of what is

[5] For the sake of brevity, countries will be categorized as "scientifically" advanced, proficient, developing, or lagging rather than "scientifically- and technologically" advanced, proficient, developing, or lagging. The latter term is more accurate, and use of the shorter term does not imply any bias against technological capacity.

[6] Differences span a continuum of the policy characteristics presented in this chapter and explored in more depth in Volume Two, Table 10, p. 27 and Appendix 2 of this volume.

important in functioning S&T systems. The benefits of S&T come through diffusion of knowledge, and its translation into goods and services via technological applications and engineering. These applications could be in classical industrial sectors like manufacturing, or in other sectors such as health, agriculture, and natural resource management. The vast majority of an S&T workforce uses what a very few have discovered, adapting, converting and applying knowledge locally. Indeed, the main value of S&T in education is to create the human capacity to comprehend and apply, not to advance, knowledge in a given discipline.

Aiming policy to build this broader capacity for application of knowledge is especially important for developing countries. Initially, the bulk of benefits are likely to accrue from thousands of small scale technological improvements in small and medium enterprises (SMEs), not through investments in large-scale corporate labs. Improved technology development at the SME level, however, helps create income that can finance, among other things, future investments in S&T.

For highly resource-constrained countries, focusing on knowledge advancement or cutting edge research is costly and unwise. Clearly, no country or culture, rich or poor, has more inherent potential or talent for advancing knowledge than any other. But rich countries have, through decades of continuous investment in human capacity and institutions, built infrastructures that better allow the potential of science and technology as a social endeavor to flourish. Once in place, the infrastructure helps create the wealth that funds future investment. At the same time, the infrastructure acts as a global magnet, drawing into itself talented individuals from abroad. Countries wishing to reap the benefits of S&T should seek to put in place this broad infrastructure that captures existing knowledge, and employs it in wealth-enhancing investments in improved health, environment, and technology development for economic opportunity. This is the surest path towards fuller eventual participation in knowledge generation and cutting edge research.

The list of issues for which developing countries need scientific and technological expertise grows longer daily: agricultural productivity, health, sustainable use of natural resources, education, creation of economic opportunity, etc.. At the same time, scientific advances are defining new challenges (e.g., the environmental and human health issues associated with genetically-modified organisms) that many countries find themselves poorly prepared to handle, given the increasingly sizeable divide separating the scientifically advanced OECD countries from the rest.

Science and technology capacity is not the only factor relevant to development. It is one component within a set of factors—along with policies favorable to competition, sound fiscal and macroeconomic policies, accessible quality education, affordable and accessible health services, and good governance—that build the climate for investment, growth, and empowerment. These factors are mutually dependent, and strength in complementary institutions becomes more important to science and technology the more deeply they permeate a society and economy. At the same time, the stronger complementary institutions and policies become, the more S&T can contribute to overall development.

The Importance of S&T to Development

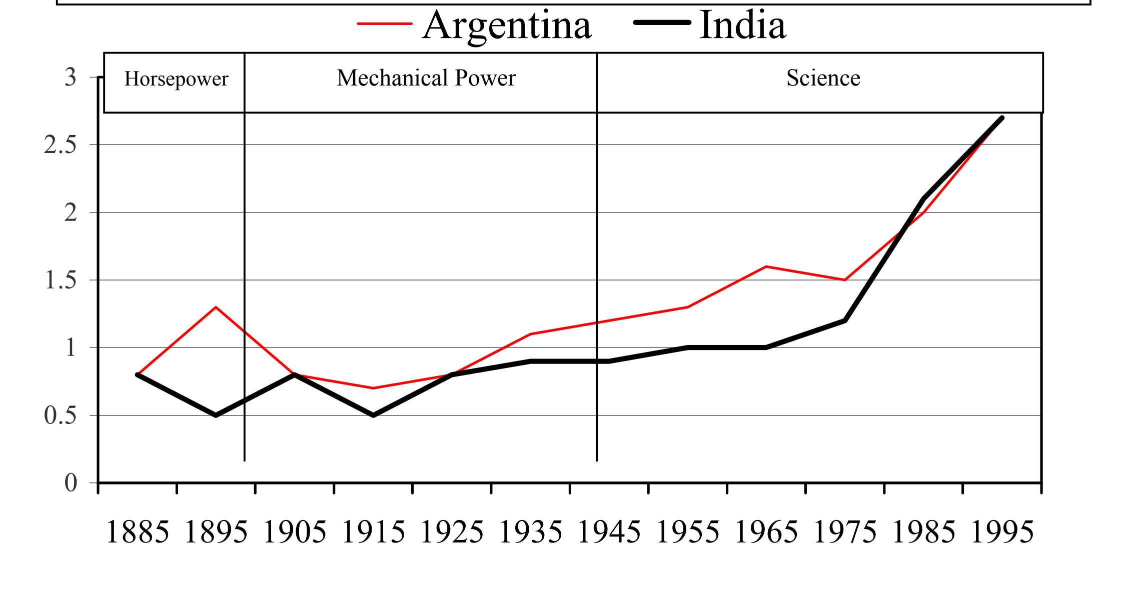
Science and technology are intimately connected with development because: (i) they have a historical record of bringing advances that have led to healthier, longer, wealthier and more productive lives and (ii) they are key ingredients to solutions to the most serious poverty alleviation and economic development challenges that we currently face and are likely to face in the future. The many ways in which science and technology impact poverty alleviation and economic growth merit attention.

For Poverty Alleviation

Advances in science and technology are, in many ways, the ultimate Global Public Good: once discovered, their benefits can be extended to additional users at little or no marginal costs. In the most basic and critical areas of human need, science and technology have made possible significant progress to date, and they hold the best prospects for continued progress, particularly with respect to agriculture, health, energy, water, and environmental concerns.

Agriculture: In the domain of food security, advances in S&T provided the foundation for the Green Revolution, and have allowed food prices to remain at historical lows for the past several decades. Improved knowledge of plant biology and breeding techniques led to better seeds and cultivation practices that drastically increased yields [See Figure 1]. Not surprisingly, Africa, the region of the world with the lowest indicators for S&T capacity, has had the greatest difficulty in capitalizing on and benefiting from the Green Revolution. Throughout the rest of the developing world, yields rose much faster than the population increased, mitigating pressures to extend cultivation to scarce additional land. It is estimated that, without the scientific advances of the past 50 years, an additional land area the size of Europe would be required to produce the world's current agricultural output. Nonetheless, over 800 million people remain food insecure, and global food production will have to double in the next 30 to 50 years to keep pace with growing demand. Rapid advances in the understanding of plant biology and related areas (especially via genomics) hold hope for solutions to problems as varied as increased productivity, nutritional content of food, food as a carrier of vaccines, soil/land degradation, post-harvest loss, and drought and pest resistance. Unfortunately, the majority of cutting edge research in these fields is performed in private laboratories and focuses on profit opportunities in OECD countries rather than on issues that are of greatest concern to the well being of poor people.

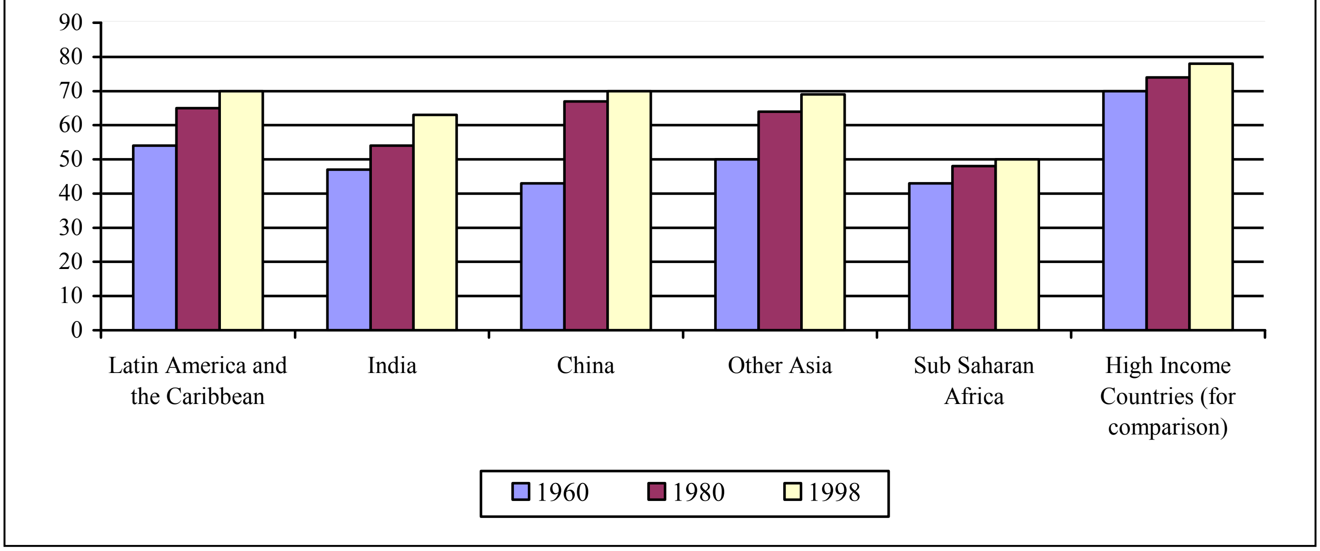
FIGURE 1: WHEAT YIELDS IN ARGENTINA AND INDIA CORRELATING TO THE SCIENTIFIC REVOLUTION (Average Annual Yields in 1,000 Kilograms/Hectare)



Adapted from Pardey, Chang-Kang and Alton 2001.

Health: Ill-health is both a cause and a consequence of poverty. Over the past century, science and technology provided the basis for the largest ever aggregate improvements in human health. Life expectancy is up sharply worldwide [See Figure 2 on the following page]. Certain scourge diseases have been eliminated, (e.g., smallpox) while the morbidity and mortality associated with everyday health-related events like childbirth and routine infectious disease have declined sharply. In health, the cumulative effects of scientific advances are very evident: while health indicators have always varied with income, during the 20th Century, the same real increase in income led to progressively greater health improvements. As knowledge accumulates, the same money buys increasingly better health. Still, progress is good but uneven. The developing world still accounts for a disproportionate amount of the global burden of disease, and research spending on health is severely skewed away from the concerns of developing countries. Far too many countries are trapped in cycles of “high-fertility, high mortality” that the world’s better-off countries have broken. Indoor air pollution, dysentery, water-borne disease (e.g., cholera), vector-borne disease (e.g., malaria, dengue, etc.) and AIDS account for millions of deaths annually and are hitting hardest the countries that are least prepared and can least afford to deal with them. Some of the issues can be addressed using current knowledge, (e.g., dysentery) while others need scientific breakthroughs in S&T (e.g., AIDS and malaria).

Figure 2: Life Expectancy at Birth in the Developing World



Box 1: The Complex Relationship Between Knowledge, Diffusion, and Outcomes: Advances in S&T Make Possible—But Do Not Guarantee—Progress Against Poverty

Examples from the health sector underscore the complicated relationship between the discovery of knowledge, its diffusion and translation into services, and outcomes that depend on behavioral change. It is the case that, thanks to advancements in the understanding of the biological basis of human health, many diseases and conditions have inexpensive and simple cures. The majority of these diseases have been eliminated or controlled in the developed world but continue to plague the developing world. This is why, in aggregate, the global burden of disease falls disproportionately on developing countries. Diarrhea, for example, still kills many infants in the developing world despite the almost universal availability of a cheap and easy oral rehydration remedy. In the developed world the same condition is rarely ever fatal.

What accounts for the different outcomes? The answer is not simple, but it most likely revolves around the depth to which science and technology permeate a society, including the level of scientific literacy of the populace. Research from the health sector shows that improved health practices were adopted in the US in the early 20th Century after the germ theory of disease had become "common knowledge." [See *The World Development Report* 1993].

However, individual knowledge alone does not tell the whole story. Resources, infrastructure, strength of institutions and quality of policies are also key: basic health services and/or public education campaigns against conditions like dengue fever, and AIDS, or in favor of pre-natal health can have a strong impact on health outcomes.

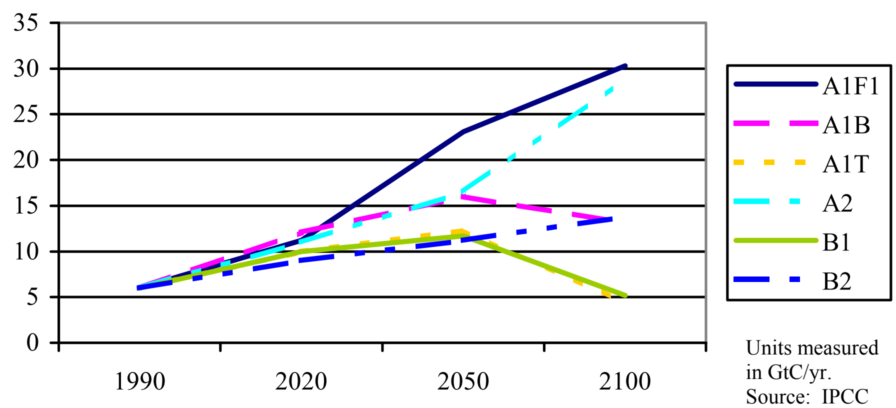
Finally, human elements, including cultural and individual behavior patterns, play a role even where knowledge is diffused and services are available. Knowledge by itself is not always sufficient to solve a problem. Nevertheless, without scientific and technological knowledge and its supporting infrastructure, improved outcomes are not possible.

Continued on following page…

***Box 1** continued…*
The factors that influence the relationship between knowledge, diffusion and outcomes in the health sector are most likely similar in other spheres, including in agricultural productivity or in technology development in industry. Research in the 1980's first linked agricultural productivity to years of schooling for rural farmers; further research suggests that even elementary concepts of chemistry and plant biology were correlated to more proficient use of fertilizer among Kenyan farmers [Jamison and Moock 1984]. Technology diffusion and use depends in part on the scientific literacy of the populace as it is determined by a country's education system, by special initiatives that seek to diffuse knowledge, by other incentives and by the human element of cultural and individual behavior patterns. Some, though not all, factors are amenable to improvement through government action, and successful outcomes can be influenced with concerted action. But if knowledge and a critical level of generalized understanding of science are not present, no progress is possible.

Energy: Despite its importance to economic growth and poverty alleviation, energy continues to be exploited in a short-sighted and unsustainable way. Unfortunately many countries are promoting fossil fuel energy policies and practices that are causing environmental degradation at the local (particulates and smog), regional (acid deposition) and global (climate change) scales, leading to significant loss of human life and ecological damage. Currently, two billion people in the world are without electricity. A central question to be answered in addressing the energy needs of this one third of earth's population is—how do we adequately address the growing energy needs of the world's population without exploiting the natural resource base and compromising the environment? Modern clean, renewable energy technologies (e.g., solar, wind, modern biomass) need to be developed further and there needs to be an increase in the efficiency and sustainability of energy use in transportation, industry, and housing. Depending upon projections of population and economic growth, technology change and the growth rate of different information markets and governance structures, global primary energy use by 2100 is predicted to range from a low of 514 EJ to a high of 2,683 EJ, while CO_2 emissions are predicted to increase to between 2.7 Gt and 36.7 Gt [IPCC 2000].[7]

Figure 3: Projected CO_2 Emissions, Six Possible Scenarios, 1990-2100



Units measured in GtC/yr. Source: IPCC [2000].

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[7] Emissions scenarios coded in Figure 3 correlate with the six illustrative scenarios used by the IPCC in their 2000 publication *Emissions Scenarios*. See publication for description of scenario characteristics.

Water: Water is another vital but scarce resource for which, in the absence of technological innovation, current and projected use patterns can only lead to severe crises. Today, about 1.3 billion people lack access to an adequate supply of safe water, two billion people do not have access to adequate sanitation, and water pollution causes millions of preventable deaths each year, especially among children. Water pollution is expected to continue to degrade freshwater and marine ecosystems, with a significant loss of biodiversity. The challenge is to leverage new technologies to provide an adequate supply of "safe" water in urban and rural areas to all users in a growing-wealthier population: households, agriculture and industrial sectors (e.g., inexpensive desalination technologies).

Environment: Environmental degradation at the local, regional and global scale adversely affects the livelihoods, health and vulnerability of poor people. Local issues include indoor and outdoor air pollution and water pollution, regional issues include acid deposition, and global issues include climate change, stratospheric ozone depletion, loss of biological diversity, land degradation and desertification. These changes in the environment can adversely affect the incomes of poor people who depend on natural resources for their livelihood. These changes may also adversely affect human health through air and water pollution, an increase in the exposure to vector-borne diseases such as malaria and dengue, and an increase the vulnerability of poor people to extreme weather phenomena (e.g., floods and droughts) and sea level rise due to climate change. Hence, environmental degradation threatens poverty alleviation and long-term sustainable development.

The key challenge is to recognize that local, regional and global environmental issues are inextricably linked and affect sustainable development. Therefore, there are synergistic opportunities to develop more effective response options to these environmental issues that enhance benefits, reduce costs, and more sustainably meet human needs. The capacity of countries to adapt and mitigate can be enhanced when environmental policies are integrated with national development policies.

For Economic Growth

Science and technology are strategically important to economic opportunity and growth. Policymakers have long suspected a close link between economic growth and productive investments in S&T, and now mounting evidence supports this, in three principal ways.

First, since the industrial revolution, rich (developed) countries have had the most S&T capacity and have grown fastest. From 1870 to the present, scientifically- and technologically-advanced countries have become increasingly wealthy, and their rates of growth have not diminished as this occurred [Pritchett, *Divergence Big Time* 1995].

Second, returns to R&D have been shown to be consistently positive and high across virtually all industries examined, in the developed and (more recently) the developing world. These findings have helped establish a correlation between innovation and growth. In a host of categories, different measures of knowledge inputs to production continue to increase, and measures of the returns to these inputs outstrip those to less knowledge-intensive production. The evidence confirming the positive returns to investments in knowledge is vast. Recent meta-analyses summarized 57 published studies of rates of return to industrial R&D at both the firm and the industry level [OECD 2001] and 292 published studies of agricultural R&D demonstrated consistent high double digit returns [Pardey 2001].

Third, and perhaps most important from the perspective of the World Bank, technological capacity appears to be contributing to accelerated growth in some large developing countries (e.g., China, India, Brazil, Mexico, Philippines, Thailand, Malaysia). High tech manufacturing exports have grown faster than all other categories and developing countries are gaining a larger share of this expanding trade. These developing countries, which are now benefiting from a combination of technological capacity, openness to trade and other comparative advantages (such as lower wages), are also experiencing accelerated rates of economic growth. What is more, the countries benefiting are home to over half the world's population, and more than half of the world's poor. Additional evidence [Dollar and Kraay, 2001] shows that incomes of poor people are rising proportionally with growth rates.

Table 4a and Figures 4b and 4c on the following page present the quantitative evidence for the correlation between increased technology content of exports and GDP growth.[8]

[8] For an annotated listing of recommended reading relevant to S&T and economic growth as well as S&T and each of the sectors covered in the preceding sections, consult the annotated bibliography in ***Annex 6 of Volume Two***.

Table 4a : High Tech Manufactured Exports by Are Growing Faster than all Other Technological Categories (Lall, 1998)			
Product Category	**1980 share (%) of total trade**	**1996 share (%) of total trade**	**Annual average growth rate, 1980-96**
Resource-based	19.5	13.7	5.7
Low Tech	25.3	21.3	6.9
Medium Tech	38.6	37.2	7.8
High Tech	*16.5*	*27.7*	*11.6*
Total	100	100	**8.1**

Figure 4b: Increases in High Tech Manufactured Exports…

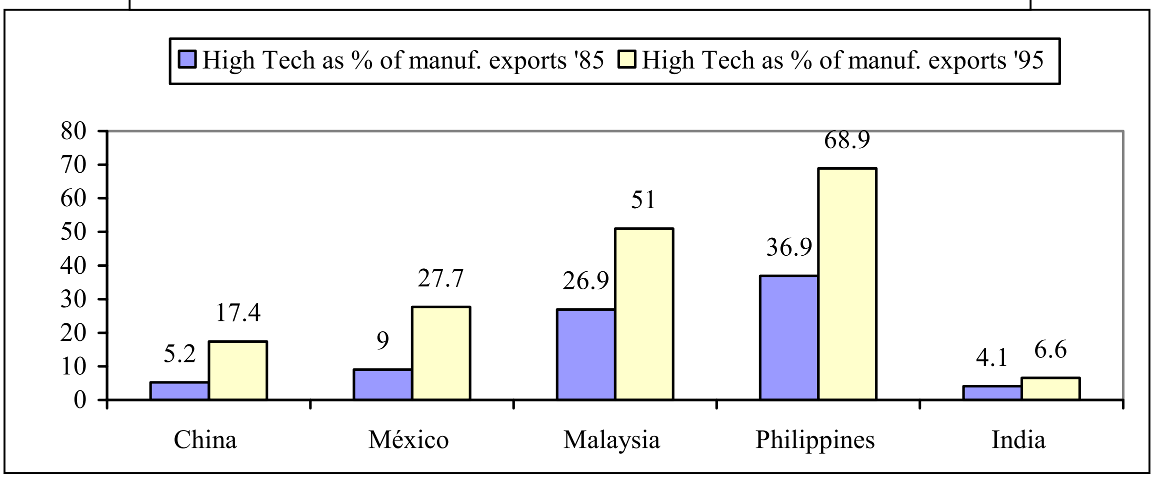
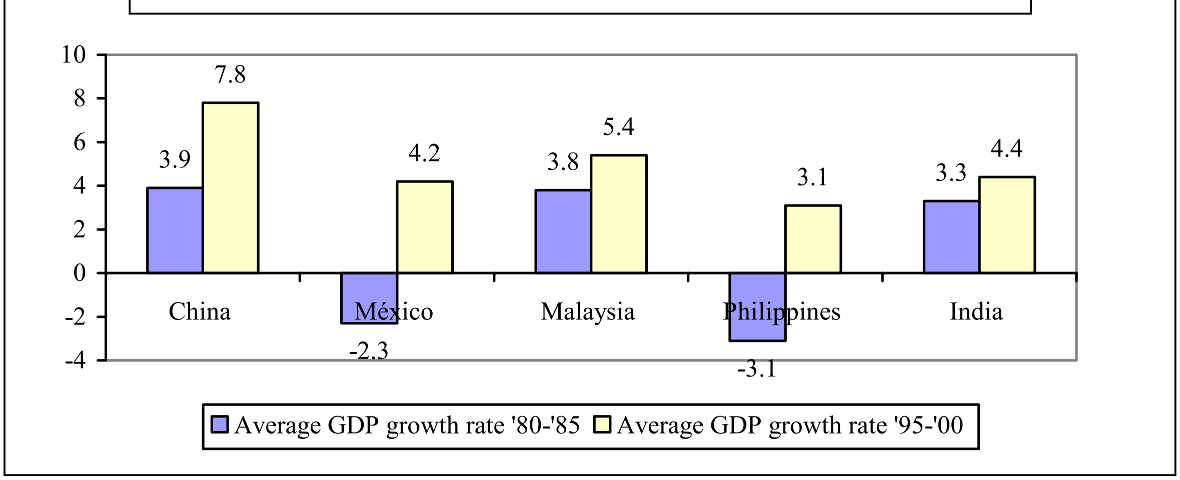


Figure 4c: …Correlate with GDP Growth



Policy Options for Reaping the Benefits of S&T

The effects of S&T on poverty and economic growth underlie their importance for development. However, achieving progress in S&T capacity depends on good policies and practices that foster the appropriate environment implemented consistently over the long term. The framework for these policies must recognize the interconnectedness of the areas upon which S&T bears. Policies that affect human resources development, demand for knowledge from the private sector, public support for and management of knowledge institutions, and access to information and communication technologies (ICT) infrastructure must be coordinated and harmonized in order to create the conditions in which S&T capacity deepens and consolidates. Each of these areas, which are detailed in brief in the following pages, entail a set of specific sub-policies, yet success depends on integrating them harmoniously. Different countries, of course, face different challenges that require emphasis in one area or another.[9]

Policies for Human Resources Development Policies concerned with human resource development seek to accomplish four major goals that are briefly highlighted below.

- Provide the broad basic science education that makes a populace scientifically literate, imparting both everyday skills and intellectual abilities needed for an informed citizenship
- Stimulate interest and prepare adequate numbers of young people to pursue careers in science and technology as well as provide opportunities for life-long learning and skill renewal
- Educate a diverse labor force and develops skills for various purposes at various levels of sophistication
- Encourage the conduct of research and advanced training that creates the knowledge and highly trained specialists needed to advance the frontiers of knowledge and applications

Sound human resources development for S&T begins with science education at the primary and secondary levels. Student achievement outcomes in science in much of the developing world are very low.[10] Of course, many of the problems of science education at primary and secondary levels cannot be separated from the more generalized challenges in basic education, such as teacher training and recruitment, stable education finance, availability of teaching materials, etc. Other challenges are specific to the domain of S&T. These include curricula that are appropriate and science programs tailored to the developmental needs of students and their societies, the use of goals and standards for student achievement to guide the design, implementation, and assessment of all elements of the science program, and provision of support systems for teachers that align with the goals of the science program.

[9] ***Appendix 2*** summarizes how the policy area of emphasis for S&T growth differs with the varying capacities of developing countries.

[10] See the results from the TIMSS for a more detailed description at www.timss.bc.edu.

As students progress through the education system, scientific and technological education opportunities should deepen and differentiate. Between the general scientific literacy that is part of secondary education, and the advanced programs pursued by university-bound students, a critical middle level of technical skill needs to be developed. Secondary-level science education should stimulate learners and encourage students to pursue careers in S&T, whether as technicians, engineers, or researchers. To do this, and to provide opportunities for life-long learning and skill-updating requires an array of technical and professional schools, community colleges, and other intermediate S&T institutions. Technical and professional schools often seek to provide mid-level technical skill to large numbers of students in areas with strong immediate labor market demand.

More advanced training opportunities will be offered by a different set of institutions within a country's tertiary education system. These might include regional and national universities, as well as research universities and institutes. Often, research universities and institutes are the locus of a country's main efforts in knowledge production and advanced human capital training in S&T. Without the necessary policies that encourage the proper functioning, growth and reform of the diverse institutions that work together to educate a country's populace, it is unlikely the resulting workforce will be trained in the relevant skills needed to drive a complex and growing economy. The reform and improvement of tertiary education systems is a domain unto itself, and the challenges here are many and important. Options for reform in higher education generally are discussed in the Bank's 2002 higher education paper, "Constructing Knowledge Societies: New Challenges for Tertiary Education." That paper and this one are complementary and are intended to be read and disseminated together.

Promoting research quality is a delicate institutional balancing act. Some issues are general and affect tertiary education and research institutions of all types. These pertain to the quality of faculty, the relevancy of curricula, the adequacy of physical resources, the flexibility and autonomy of institutional management, and the sources and stability of financing. A major challenge facing developing countries is how they can meet the growing demand for tertiary education while simultaneously improving quality and relevance, within shrinking public budgets. The growing role for the private sector in higher education is another phenomenon that requires attention. These issues acutely affect education in science and engineering, which tends to be more complex and expensive, particularly in research-intensive subdisciplines.

Other issues are specific to science and technology itself; they revolve around assuring the linkages between graduate education and publicly-funded, university-performed research. The latter relies on competitive allocation procedures; transparency, and peer review; research evaluation and accountability for results; special programs, national priorities, and perhaps most important, the adaptability of the system to changing conditions and new challenges. Another critical issue in tertiary education is how to balance public support for foreign and domestic training to strengthen domestic capabilities and avoid brain-drain by individuals educated at public expense.

<u>Policies for Stimulating Demand for Knowledge in the Private Sector</u> Highly skilled human resources for science and technology cannot in and of themselves produce benefits for a society. They must act within a structure in which the private sector requires and seeks knowledge. Countries that have transformed their economies and dramatically improved income levels have done so by improving the technological performance of their industries within supporting investment climates. They have deepened their technological capabilities to the point where they can consistently and successfully compete on a global scale in a growing number of industries. They have recognized that economic performance is more sustainable when it is founded on the dynamic advantage of flexible production and cost reduction, rather than on the static advantage of low-cost labor or factor endowments. They have combined policies for investment that encourage and reward entrepreneurship with those that facilitate the greatest flow and use of commercially-relevant knowledge. Each experience has been different, but some basic lessons have emerged. Transformations did not occur overnight; in general, they required two to three decades of sustained national effort. In general, countries did not "leapfrog" from archaic to modern technologies. Instead, as one observer put it, "they engaged in a painstaking and cumulative process of technological learning (from imitation to innovation)."[11] In many cases, they focused a broad-based strategy on technology development at the level of the SME, rather than on support to cutting edge R&D.

Demand for knowledge in the private sector should not be limited to classical industrial sectors such as manufacturing. It is equally important to stimulate this demand in areas such as agricultural productivity, health services, energy services and natural resource management, in both firms and government institutions.

"Implicit policies for S&T", which create an environment for investments in scientific and technological undertakings, are virtually identical to those that build the climate for investment, jobs, sustainable growth and empowerment of poor people. These may include, but are not limited to:

- ***Basic Macroeconomic Stability***. While desirable for a host of reasons, avoidance of fiscal and monetary crises helps provide the stability and continuity needed for the finance of research and commercialization.
- ***Openness to Trade and Foreign Direct Investment***. While some countries have managed to improve scientific capacity and technological performance through strictly domestic measures, the weight of the evidence is showing more cases in which trade and FDI were critical conduits for the technology transfers that spurred growth.[12]

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[11] Bezanson, Keith, and Geoffrey Oldham, "A Science Technology and Industry Strategy for Vietnam," p.37. This section of the paper draws on this work as well as on conversations with the authors.
[12] Openness to trade may often accompany growth that is fueled by technology development, but it is not true that openness is an indispensable prerequisite for S&T-led growth in all cases. Some countries have developed strong industrial bases with relatively closed economies. Openness, like the other items mentioned here, might be best considered a likely associated condition, to which there are exceptions. See Nelson, Richard *National Innovation Systems: A Comparative Analysis* (New York: Oxford University Press) for further detail.

- ***Credit Policies***. If a diverse set of financial instruments (loans, equity financing, venture capital, etc.) do not evolve as technological capacity increases, industrial development can be stifled.
- ***Intellectual Property Rights Protection***. Adequate IPR protection is thought to play a strong role in creating incentives for R&D and innovation, and in promoting the diffusion of knowledge.
- ***Competition Policy***. Policies that create a level playing field and facilitate the entry and exit of firms into new markets stimulate innovation and commercialization of new technologies.
- ***Provision of Industrial Standards***. This can either take the form of a pure public good, in which the government creates and maintains standards that permit technology based commerce, or, simply creating an atmosphere in which firms themselves agree on such standards to facilitate open interchange and use of specific technologies.

In addition, a number of "explicit" policies may be appropriate at the level of the firm. Such policies are generally intended to overcome information barriers to understanding or appreciating the potential benefits of R&D, or to lower the cost of risk-taking. This may be accomplished through a variety of interventions that foment strong university/industry relations, including tax or other incentives to firms for cooperative pre-competitive research, commercialization of publicly-financed research, sponsorship of "scientist-in-industry" programs, provision of joint or specialized training, and other similar activities. Success in industry-science relations often relies on informal, person-to-person links that are best promoted through a diverse set of interactions, which create cultures of information exchange. Successful cultures of this kind seem to emerge when labor is mobile, incentives are aligned, basic research results are shared, and rigorous evaluation of research is conducted. The creation of shared infrastructure for new firms in the form of technology parks or "incubators" can be a means of promoting the desired interactions, but such ventures have a mixed empirical record of success. Best practice lessons are now emerging for technology parks and incubators that reflect the need for long time horizons for commercial sustainability, careful matching of target markets with the strengths and ambitions of potential firms, and proximity and linkages to top quality research institutes and universities.[13]

Policies for Public Support of S&T The public sector has played a significant role in all countries that have developed strong S&T capacity. This role should have clear boundaries, limited in many cases to identifying priorities, creating incentives and frameworks, funding basic research, and providing S&T-related public goods. Lately, the role also involves stimulating linkages between public and private sector entities. Nonetheless, public action will always be a part of the creation and maintenance of an S&T system, as many of its features have public goods characteristics and would be undersupplied by the market alone.

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[13] For a more detailed look at the way in which demand is stimulated in the private sector, ***Volume Two, Annex 5*** provides a study of the role of the private sector in facilitating the acquisition of technology in developing countries.

The proper functioning of the public sector, be it with respect to the private sector, education and training, or technology transfer and information flows, is critical to the creation and maintenance of a well-functioning S&T system. Conceptually, the public role can be disaggregated into five functions:

- Setting priorities for public sector financing
- Directly financing some parts of the system
- Governing, regulating, and (partially) managing the system
- Incorporating the results of research into public policy decisions
- Monitoring and evaluating the system to ensure accountability and relevance

These responsibilities come together in a cycle of continuous revision and formulation of S&T policies that determines the size, character, and effectiveness of a given system. Effective S&T systems emerge when governments are constantly engaged in this cycle of priority setting, policy formulation and implementation, execution, use, monitoring, and evaluation.

One such area in which a number of functions come together, requiring a knowledgeable yet flexible government is that of setting the research agenda. The goal is to strike the proper balance between the need for basic and applied research while achieving breadth that connects research to important national priorities. Box 2 considers the ways in which these issues are evolving in the policy sphere.

Box 2: Basic Versus Applied Research

One question often asked of developing countries is whether they should support basic research or focus only on applied research that is consistent with the estimated needs of the private sector. The Third World Academy of Sciences as well as most Academies of Sciences throughout the world would agree that this distinction between basic and applied is too simplistic. Basic and applied research are part of a continuum with poorly defined borders.

From one perspective, the discovery of enzymes that cut and rejoin DNA nucleotides was a triumph of basic science: the desire to understand the ways cells work at the molecular level yielded new information that extended our collective knowledge of these important fundamental processes in nature. From another perspective, these same discoveries immediately made a critical technology available around which a new industry called "biotechnology" could be built. So was it basic science or was it applied work?

A better question is whether the "basic/applied" distinction is still a meaningful lens through which to view research policy. In some disciplines, like Biology/Life Sciences, it almost certainly is not. The line between furthering basic understanding of natural processes and the development of potential applications is hazy and overlapping, and the time from discovery to commercialization can be exceedingly short.

Policy-makers rarely know which scientific research is most likely to spawn useful and productive applications. They can, however, create environments that maximize the incentives for commercialization and discourage consistently irrelevant work. Research policy is more often effective when it concerns itself with the overall environment for commercialization, and shies away from "picking winners" or prioritizing one type of research over the other according to the increasingly obsolete distinction between basic and applied research.

The challenge in this policy area is to provide effective public support for S&T through a variety of channels simultaneously. First, governments must set national priorities and assure that the S&T system is diversified and decentralized, again, balancing concentration of resources in centers of excellence with stimulating large-scale and dispersed research efforts. Second, they must play major roles in organizing and sustaining education systems and sectoral ministries that either produce or require S&T inputs and outputs. This is done through balancing their roles as producers, consumers, financers, managers, and regulators/controllers of quality for research and its accompanying human resources training. Third, it is also necessary for governments to play a critical role in establishing the rules of the game of S&T resource allocation. A major part of this involves promoting transparency, objectivity, and peer review and evaluation procedures, assuring that merit and performance are the criteria for determining how to award discretionary research funding. Fourth, governments must seek to inform their policy decisions with the necessary scientific data. Finally, as monitors and evaluators of a transparent and impartial S&T system, the government has a role to ensure that women and other traditionally-excluded groups have access to the same opportunities as men to build and advance careers in science and technology.

Policies to Promote Adequate ICT Infrastructure Information flows are an essential part of the overall structure that promotes the use of knowledge. Adequate information and communication technologies (ICT) infrastructure is now indispensable to ensure access to the global stock of knowledge and information on which innovation depends. ICT infrastructure has created new channels that rout information more efficiently, reducing transaction costs and making possible new and/or greater economic opportunities. In research specifically, new technologies for information storage, organization, and sharing are changing the nature of research in a number of fields. New disciplines like bioinformatics concern themselves exclusively with the discovery and organization of massive quantities of data on living organisms.

As in other areas for S&T capacity building, the challenge for the vast majority of developing countries is to access available ICTs rather than to generate new ICT research. Policies that expedite the process of helping cities, regions and whole countries to become physically wired are critical to narrowing the divide between the scientifically advanced and the scientifically lagging. The nexus between private industry, educational systems and the pubic sector stands to gain as well from improvements in ICT capability as connectivity fosters communities of knowledge and practice capable of addressing innumerable cross-sectoral development-related objectives. Countries that lack adequate ICT infrastructure are excluded from the efficiency gains related to ICT modernization and the opportunity to benefit from further knowledge made available in ICT-dependent forms, as explored in more depth in the recently released ICT Sector Strategy Paper.

Coordinating the Four Policy Areas: The Importance of Monitoring, Evaluation, and Dialogue. Because each of the four aforementioned policy areas is conceptually discrete, any description is bound to make the policy formulation sound formulaic. In reality, formulation and coordination of policies across these domains is a dynamic and on-going process. It requires a subtle appreciation on the part of governments as to their role and a deft touch in knowing how and where to be involved or not. It also requires a factual grounding that can only come from careful monitoring, collection of indicators, and evaluation. Here, many developing countries are completely without experience. With the exception of larger, middle-income countries, data are scarce and the amount and quality of dialogue is inadequate. The challenge is to convert the growing interest of politicians in S&T into opportunities for dialogue on policy and performance, within an integrated and coordinated framework for S&T in development.

The role of government in the promotion of S&T is a combination of a number of responsibilities. In addition to the specific areas mentioned earlier in this paper, it involves the inclusion of S&T-related policies in all levels of education, in industrial policy and the entire legal framework that governs business environments, as well as in any number of specific concerns of "line Ministries" (agriculture, health, energy, environment, transportation, and others). The need for coordination is substantial, as is a sound judgment in deciding on the types of action needed across the various sectors. Good science and technology policy is the aggregate of appropriate decisions on frameworks, incentives, direct support, and evaluation/policy analysis across this spectrum.

Lessons from Previous Experience World Bank Experience in Promoting S&T Capacity

In a variety of forms, improving S&T has been a concern of the World Bank for decades. It is worthwhile to extract the lessons of the past when considering directions for future action. However, analyzing previous experience of donors and multi-laterals is difficult because S&T is a cross-cutting theme. Lessons must be mined from a continuum of sector-specific initiatives in agriculture, health, education, energy, environment, private sector development, and other domains in which S&T is a key ingredient but not the dominant concern. Nonetheless, analysis of previous experience does lead to several lessons specific to the four policy areas as well as some overall cross-sectoral conclusions.

The World Bank has supported S&T capacity in (i) education projects; (ii) industrial technology development and other private sector development projects; (iii) agriculture research and extension projects; and, (iv) information and communication technologies projects. Still, apart from Agriculture/Rural Development, and select middle-income countries in East Asia and Latin America, Regions and Networks have not treated S&T in development in a consistent and systematic way. A number of activities outside of lending operations have been supported by grants from the Development Grant Facility, but again with no systematic attention to S&T capacity building for the long term.

Specific quantitative analysis of World Bank operational support to S&T reveals that:

- Between 1980 and 1999, the World Bank lent $7.8 billion to directly support S&T activities across 590 projects, though fewer than 100 of these contained a significant S&T capacity building component. Annually, 30 S&T projects were sponsored, with average lending for S&T totaling $390 million. Five projects a year provided major support for S&T (greater than $10 million) and twenty five projects a year provided minor support for S&T (less than $10 million).
- Most major support for S&T (outside of agriculture) went to a handful of large, middle-income countries.
- Regionally, East Asia received half of all major S&T loans during the review period. The next most frequent S&T borrower, Latin America, took out nearly one-fifth of the loans.
- The DGF provides close to $100 million annually for programs that are S&T-related.
- The World Bank itself is a funder of global public goods research for development. In some disciplines, such as development economics, funding and publications constitute a significant portion of the input and output for the discipline.

Lessons from the World Bank's diverse experience with S&T are summarized below.[14]

Lessons from World Bank experience in human resources development Three major conclusions from the World Bank's involvement in basic and tertiary education emerge. First, attention to science education has been limited at the primary and secondary levels in both policy dialogue and lending. The support provided has typically prioritized equipment over teacher training, curriculum development, and improving assessment, although somewhat less so recently. Second, sufficient attention has not been given to improving learning outcomes in science. The international assessments of student learning outcomes in science have not been meaningfully incorporated into the World Bank's support for science. By encouraging World Bank clients to participate in international assessments (e.g., the Trends in International Mathematics and Science Study (TIMSS) and the Program for International Student Assessment (PISA)) the World Bank could encourage monitoring and benchmarking of both student progress and teacher training efforts. The third lesson from the World Bank's involvement with S&T education, tertiary in particular, is that the overlap between academic training and research and the private sector stands as an important nexus of capacity and use. Tertiary education systems are often the final stage of training for labor market entrants with advanced scientific skills. Creating the right "backward" linkages to the broad reform agenda for tertiary education (e.g., quality assurance,

[14] A more detailed qualitative and qualitative analysis is available in ***Volume Two, Annex 2***. Similarly, lessons from bilateral, NGO, and foundation experience are discussed briefly here and more in depth in Volume Two as well as in ***Volume Two, Annex 2***.

finance, coverage, equity, institutional governance and management, diversification) and the forward linkages to the private sector are both critical steps needed to ensure the successful use of S&T-educated people for social and economic ends.

Lessons from World Bank experience in stimulating demand for knowledge in the private sector The World Bank has fostered a demand for knowledge in the private sector in two ways: by working to improve the overall macroeconomic conditions of its client countries and by directly investing in private sector and industrial technology development activities. With respect to the former, OED evaluations conclude that, on average, adjustment operations have done well in helping countries lay a foundation for accelerating growth, improving macroeconomic conditions, lowering inflation and removing the economic distortions that are damaging for productivity growth. To the extent that such efforts are successful, they will continue to help build a conducive environment in which S&T can grow and flourish. Lessons from industrial technology development (ITD) show that the success of ITD projects is contingent upon the presence of a well-articulated technology strategy at the national level. Many of the larger, fast growing countries—such as Korea and Singapore—that had such well-crafted policies in place experienced positive S&T-led growth following subsequent investments in ITD. However, some knowledgeable observers commented that an unwillingness on the part of the World Bank regarding projects that require government interventions for technology development led to a discontinuation of ITD projects in the mid-1990's despite their success.

Also in its review of ITD projects, the OED identified science and technology's disconnect from the private sector as an important obstacle to be overcome. To better foster the necessary linkages and enable ITD's contribution to knowledge development and enhancement, several key actions are suggested, including the need for a core group of specialized staff with interest and expertise in technology lending activities, better dissemination of technology literature within the World Bank to stimulate more discussion on the matter, and at the country level, an emphasis on private sector institutions and their linkages between SMEs and R&D institutes to narrow the divide existing between the private sector and knowledge-generating institutions.

Lessons learned from fostering partnerships between the private and public sectors serve to reinforce the notion that successful S&T capacity building requires linkages between these two spheres. Two examples taken from the US, but which could equally be drawn from the vast OECD experience, illustrate the point. The US National Science Foundation helped foster more than a dozen Engineering and Science and Technology Research Centers, by providing ten years of core funding under a decreasing "sunset" clause. The Centers, whose mandate was to provide valuable services to industry, had to become profitable or disappear once their public funding was exhausted. The majority continue to exist as profitable, self-sustaining enterprises. In another example, private investment helped improve the efficiency of the public sector. Frustrated with the average 30 month waiting period before a drug received Food and Drug Administration (FDA) approval, the pharmaceutical industry worked with the FDA to reduce the time needed to approve drugs for the market. Through the 1992 Prescription Drug User Fee

Act (PDUFA), the FDA now collects user fees from the drug industry in exchange for meeting specific timeframes for the review of new drugs. The agency uses the additional funds it gets from user fees to augment the resources it has available for the review of new drugs. This partnership has successfully reduced the average waiting period between submission and market approval/denial to 11.6 months in 1999. Both of these examples underscore the lesson that mutual gains are achievable when the private and public sectors enter into partnership.

Lessons from World Bank experience in public support of S&T Lessons learned over the course of lending to encourage proper public support of S&T include the proven importance of creating open, transparent governance and peer review systems at the heart of S&T systems. These qualities are critical for success in priority setting as well. Other lessons learned include the tendency of the World Bank to over-emphasize physical inputs at the expense of improvements in policy to build public support for S&T. Major public sector S&T lending projects from 1980 through the mid-1990s received criticism for such an over-emphasis. Another important lesson learned is the need for sustained engagement and long term commitment, given the timeframes for change in the S&T sector.

The World Bank's response to these findings has been, inter alia, to seek to foster excellence through competitive funding mechanisms, using best practice for research management. This has taken the form of project components in higher education reform projects, such as the Quality Improvement Fund (*Fundo para el Mejoramiento de la Calidad: FOMEC)* in Argentina or the competitive funds in the Chile Higher Education Improvement Project. It has also given rise to the Millennium Science Initiative, an expanding group of projects that seek to improve the quality and efficiency of research systems through an emphasis on excellence (especially as guaranteed by competitively funded peer-reviewed grant allocations), on intense human resources training, and on relevance of research and linkage to the private sector. [See Box 3 for further details about the MSI].

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The ways in which the success realized in the MSI pilot group generalized across the entire Chilean S&T system are several. First, Chile's main funding agency has adopted the more transparent allocation processes used by the MSI. Second, researchers use the MSI as a positive example in dialogue about further improvements to Chile's system. Third, Chile has hosted regional S&T policy meetings under the auspices of the MSI. Fourth, the government has requested a follow-on project that would seek to generalize the reforms demonstrated under the MSI LIL.

Bank participation catalyzed significant changes in Chile. However, the gains realized originated first within a small pilot group consisting of the country's best researchers and were then later generalized across the Chilean system as a whole. Chile had the right conditions for this type of action, but another country might use the MSI in a very different way. Benefits do not come from support to Centers of Excellence per se, they come from demonstrating that excellence is possible with the right policies, and then from generalizing this demonstration. The Bank should continue to use the MSI to initiate action and catalyze reforms where clients seek to improve their under-performing S&T system with explicit links to the higher education systems.

Annex 4 of Volume 2 offers a more detailed description of the Millennium Science Initiative.

In Agriculture, experience has focused on building capacity in publicly-managed National Agricultural Research Systems (NARS). Despite much notable success, especially in larger middle-income countries, several issues are consistently listed as difficulties or areas in which effectiveness should be increased. First, lack of borrower commitment to sustainable funding limits NARS' success. NARS, like virtually all advanced research systems, accumulate strength and capacity slowly and are by nature extremely vulnerable to even short periods of funding scarcity or excessive fluctuation. Second, management capacity and incentive structures are often weak and inflexible. Lack of capacity in priority setting has been detrimental to relevance and efficiency. Third, more attention needs to be given to human resources development. Even the World Bank's Agricultural Sector Policy Paper published in 1980 called for an increase in the number of trained scientists in the sector (that paper projected an additional 9,000 scientists would be needed in the agricultural sector), yet, until recently, insufficient attention had been given to linking research with human resources training. Fourth, monitoring and evaluation is generally inadequate at the level of research programs and outputs as well as with respect to institutional and policy changes.

According to the analysis of Byerlee and Alex (1998), the incorporation of lessons from past experience in agricultural S&T has led to changes in lending practices, including a notable shift in priorities after 1993 toward management and policy competence, incentive systems, and accountability. The shift could be described as the adoption of a "quality agenda" that emphasizes: (i) merit and scientific rigor through the use of competitive funding, external reviews, and increased institutional linkages, (ii) sustainability of funding through a variety of mechanisms including public-private interaction, cost-recovery, endowed research foundations, and farmer financing, (iii) more recognition of and support for human resources training, especially as conducted at universities,[15] (iv) continuing efforts to reform National Agricultural Research Institutes (NARIS) and the policies that affect them, and (v) increasing "knowledge-intensive" agriculture through linkages to basic research and the international knowledge base.

Lessons from World Bank experience in ICT While the World Bank has sponsored several projects and initiatives to establish and/or improve client countries' ICT infrastructure, many of the new World Bank-funded systems are somewhat precariously situated in the client countries. Significant effort is still required to integrate these systems effectively into the societies in which they have been created to make them accessible and useful. Additionally, the World Bank has learned that investments in ICT research and extension must include concomitant investments in human capital as it is necessary to use skilled workers to implement the expansion of ICT programs beyond the initial transition phase. Recent evaluations of the World Bank's ICT work also reveal that IT activities would be more effective if they were integrated more closely with other programs related to the information infrastructure, such as those pertaining to research and private sector development and such initiatives as InfoDev. OED specifically recommends fostering essential experimentation, research and applications that can provide a basis for a more demand-led information infrastructure development program by the World Bank, which would incorporate and build upon the InfoDev program.

In response to several of the aforementioned needs identified by the OED, the World Bank's Global Information and Communication Technologies (GICT) Department now addresses four strategic areas: broadening and deepening sector and institutional reform; increasing access to information infrastructure; supporting ICT human capacity; and, supporting ICT applications. The first area helps create the overall environment for adoption of ICT, while the other three areas share specific goals with the science, technology, education, and productivity concerns that are the subject of this paper. One example of this is the ICT Strategy's emphasis on the need to build human capacity, both for general pedagogy and for sector-specific applications: "the most important use of ICT in education is as a pedagogical tool, when properly integrated into a broader educational program. However, there is also a need for ICT to be used to develop sector-specific skills and capacity." Other areas, such as fostering public-private partnership, also show significant overlap with and are complementary to the concerns of S&T in development.

Lessons from the Development Grant Facility's Support to S&T Initiatives. A review of the funding priorities of the Development Grant Facility (DGF) reinforces the critical role that S&T issues play in development. Close to two-thirds of total DGF funding goes to S&T-related programs and priorities. Some grants, such as support for the Global Forum for Health Research are at or near best practice for trying to use S&T capacity to reduce poverty. Many others fund important specific activities and form

[15] Page 63 of Byerlee and Alex notes that Bank-supported agriculture R&D projects should pay more attention to general issues of university quality and improvement, as a means to strengthening NARS. This is a potentially fruitful area of cooperation between staff in the Agriculture and Human Developments Networks.

strategic partnerships for progress against specific S&T-related problems in development. However, the weight of S&T in this important development financing instrument only serves to emphasize the need for a comprehensive strategy for S&T capacity building in World Bank client countries. Experience to date is not encouraging. The CGIAR, historically the largest DGF grant recipient, has recognized the modest gains it has made in capacity building in the developing world. Worse, perhaps, collaboration with the CGIAR in the World Bank's operational support to capacity building for agricultural research has been minimal. The most prominent lesson learned from DGF experience is that the knowledge gained from global public goods programs is not being adequately utilized in country programs.

The following table itemizes the DGF programs, by category, that relate to science and technology. The S&T-related programs constitute almost $100 million of the DGF's $145 million annual expenditures.

Table 5: DGF Financing of Science- and Technology-Related Programs (2001)

Program Category	Contribution (US$)	Program Category	Contribution (US$)
Empowerment, Security and Social Inclusion		*Communicable Diseases Continued*	
ProVention Consortium	332,500	Special Program for Research and Training in Tropical Diseases	2,500,000
Education		Global Forum for Health Research	6,925,000
Program for the Assessment of Student Achievement	1,615,000	UNAIDS and Regional Initiatives	4,000,000
Program for Education Statistics	1,070,000	Roll Back Malaria in Africa	1,500,000
Health		Stop TB Initiative	700,000
Research and Development in Human Reproduction	2,000,000	*Environment Commons*	
Population and Reproductive Health Capacity Building Programs	2,000,000	Consultative Group on International Agricultural Research (includes $500,000 for the Millennium Ecosystem Assessment)	50,000,000
Global Micronutrient Initiative	1,200,000	Critical Ecosystems Partnership Fund	5,000,000
Information and Knowledge		UN Convention to Combat Desertification	1,250,000
World Links for Development Program	750,000	Forest Partnership Program	750,000
Information for Development Program	4,000,000	The Global Water Partnership	400,000
Global Development Network	5,450,000	Natural Resource Degradation of Arid Lands	300,000
Communicable Diseases		World Resources: 2002-2003: Living in Ecosystems	150,000
Onchocerciasis Control Program	1,733,066	Solar Development Group	2,000,000
African Program for Onchocerciasis Control	2,758,798		
TOTAL DGF CONTRIBUTION to the above S&T-related programs annually			**93,184,364**
Average annual DGF Budget across all 77 priority programs			145,000,000
Science- and Technology-Relevant programs as a percentage of DGF program financing			**64%**
Source: World Bank *Compendium of Programs*, 2002.			

In short, a review of World Bank experience illustrates a history of support for S&T in which much disparate activity occurred without any coherent framework or long-term goals for improving S&T capacity in client countries. With the exception of agriculture, the World Bank has also been reactive, and focused on large, middle-income countries whose S&T infrastructure was already comparatively advanced. While World

Bank operational and grant support to S&T has been effective in some instances, it has generally occurred in vertically isolated "knowledge silos", with little connection to vitally-related activities and areas, across sectors and within them.

Lessons from Bilateral, NGO, and Foundation Experience. A small number of bilateral donors, NGO's and foundations have dedicated programs to improving S&T capacity over the past few decades. The record is mixed, but cases of success seem to have come from concentrating long-term support on well-defined sub-sectoral goals in smaller countries. This has often been the case for foundations that chose a particular problem, like malaria, and built a program around it. On the negative side, bilateral support has fluctuated enormously, with funding for research being one of the first activities to be cut when budgets are declining. This is especially damaging as continuity of support is vitally important to research and capacity building. In general, only a small sub-group of donors have made systematic attempts to: (i) give prominence and importance to improving S&T capacity as an essential long-term goal for development; (ii) approach S&T in an integral manner, emphasizing cross-sectoral connections; and (iii) reach out to smaller and poorer countries that have the greatest need and face the greatest challenges in improving their S&T capacity. Success has been notable, although it has been on a small scale with modest resources. The Nordic bilaterals and the US foundations have the longest histories, but recently the Netherlands, Switzerland, and others have increased their activities for S&T. These cases of success are a potential source of partnerships for other members of the international S&T community.

Rethinking the World Bank's Approach to Science and Technology in Development

The World Bank does not have a specific unit or section bearing central responsibility for promoting S&T capacity. Although this approach has not prevented the development of some effective initiatives in specific countries or sectors, it may have limited the Bank's ability to develop an integrated and systematic approach toward capacity improvement. To increase its effectiveness, the World Bank is exploring different means: (i) measures to increase awareness of the importance of S&T and development within the Regions and Networks, (ii) piloting multi-sectoral initiatives, (iii) integrating S&T concerns into sector strategies and CAS's; (iv) building the analytical base, and (v) creating partnerships. Any of these courses of action would be facilitated if there were a clearer locus of responsibility and sense of ownership for S&T capacity. Active synergies will be achieved by the relocation of Science and Technology to the Human Development Network as of July 2002 to more effectively promote the linkages with the Higher Education group. Further synergies within the World Bank might be achieved through the formation of a Thematic Group whose internal members are champions and leaders in S&T from the Education, Rural, Health, PSD, Energy, Environment and other sectors, as well as from the Regions. Without such a mechanism, it could prove difficult to break with the historical legacy of *ad hoc* promotion of S&T.

A multi-sectoral internal Thematic Group is advisable because the steps required to promote S&T are complex, and essentially involve creation of champions within each

Network, along with greater coordination and inter-sectoral cooperation. Creating a program for action across sectors with monitorable indicators will require a great deal of finesse and balance between core responsibilities in the sectors (e.g., Education, Health, Agriculture, etc.) that need to be pursued separately. However, if exploited, synergies among sectors could result in quantum improvements in clients' S&T capacity. The goals, processes and anticipated outcomes of the creation of the multi-sectoral Science and Technology Thematic Group are described in brief.

The Goals…

The Thematic Group would lead efforts to raise awareness of the importance of S&T within each Network and Region by coordinating, sharing knowledge, identifying and piloting inter-sectoral initiatives, and leveraging the World Bank's comparative advantage as the institution with the mandate and resources to address the four vital areas of policy that bear on S&T:

Human Capital Development. Education will continue to be the cornerstone of long-term S&T capacity building. The main challenge in education is to increase the amount and effectiveness of World Bank attention and support to scientific and technological education at all levels within the framework of general education reform. Specific actions could include:

- *Increasing the emphasis on science education in basic and secondary education lending*. This would also include encouragement and operational support for wider participation of developing countries in teacher training, curriculum development, physical investments (where appropriate), and assessment of outcomes. A starting point could be increased participation of World Bank clients in international assessments of achievement in mathematics and science.
- *Including science and technology as part of the renewed and expanded emphasis on tertiary education.* To participate more fully in the knowledge economy, more countries are seeking to strengthen the core knowledge institutions that constitute their tertiary education systems. The World Bank has increased and broadened its portfolio of tertiary education activities, placing emphasis on meeting the challenges of expanded access with quality and cost effectiveness. In some cases, tertiary education reform has also included attention to S&T issues, but this is predominately the case for large middle-income countries. The challenge is to make S&T a part of tertiary education reform for a broader spectrum of clients.

Stimulation of Demand for Technology from the Private Sector. The World Bank should explore ways to include concern for S&T as part of its important work of improving investment climates and increasing the knowledge content of economic activity. While many issues on this agenda must be carried forward simultaneously, more attention can be given to those key pressure points that induce greater use of technology in the private sector and the removal of obstacles to knowledge sharing and S&T diffusion. Among the means for achieving this are the following:

- *Renew emphasis on the creation of linkages between firms and knowledge institutions*. World Bank lending operations should continue to explore innovative means to reduce barriers and information problems that stifle greater use of knowledge in production. Stimulation of contact between university and industry, or appropriate support for the formation of clusters of knowledge-based industries are among the diverse mechanisms that can be part of a series of measures designed to increase knowledge flows in firms.
- *Reform enabling environments for better use of knowledge*. Intellectual property rights administration, as well as taxation, credit policy, and competition policy reform should routinely be included in World Bank efforts to improve the investment climate in all client countries.

Strengthening the Public Role in S&T. The nature of the World Bank's support for improving the public role in S&T is likely to vary greatly according to country circumstances. Nonetheless, interventions should revolve around:

- *Priority setting and evaluation*. As it expands to work with a greater range of client countries, the World Bank should provide support and technical assistance to help smaller, poorer countries plan and set priorities in S&T. This could involve the development of evaluation and diagnosis techniques that consider where success is most likely and how limited S&T resources can be effectively concentrated on the most socially and economically useful investments.
- *Promoting transparency, objectivity, and selectivity and international best practices in S&T funding*. One of the most effective ways the World Bank can promote long-term, sustainable improvements to national research systems is through promoting the adoption of international best practice in funding with transparent, objective peer-review selection processes. A principal means for doing this could be the expansion of the Millennium Science Initiative beyond its successful beginning in Latin America [See ***Volume Two Annex 4***].
- *The government as a consumer of knowledge.* Not only is there a role for the public sector to help fund and support knowledge-creation, but there is also a role for the government as a user of knowledge. In creating S&T-relevant policies, the public sector necessitates access to the scientific knowledge necessary to understand the likely outcomes of policy decisions, thus, there is a role for the World Bank to assist in building capacity to utilize scientific knowledge and to serve as a potential clearinghouse for some types of S&T-related information needed by public sector decision-makers.

Increasing Access to ICTs. As the core work of the Global ICT group expands, opportunities should be sought to make the S&T infrastructure more available to potentially innovative firms, knowledge institutions, national research systems, and other stakeholders. The main instrument of the World Bank will continue to be policy and regulatory reform, given its potential system-wide impact. Additionally, the World Bank should continue to focus less on the R&D aspects of new ICTs and focus its efforts primarily on widening distribution and usage across regions and countries. As called for in the recent ICT Strategy, future action will also need to prioritize support for ICT human capacity.

The Process…

The process through which the Thematic Group should pursue these goals would include building a community of practice within the World Bank that unites stakeholders and champions whose work depends on strengthened capacity in various aspects of S&T. This process would stimulate greater attention to S&T issues in each Network, coordination of key policies, and the piloting of cross-sectoral operations that take a more integrated approach to improving S&T capacity in areas that are key to development, such as:

- *Combining improvements in policy frameworks for the private sector and the tertiary education sector.* Examples of such industry-academia linkages might include specific actions in medical education, agronomy, natural resources management, or other areas.
- *Building on knowledge assessments with coordinated lending efforts across sectors (e.g., in Private Sector Development or Human Development).* Client demand is high for analytical products that demonstrate the role of knowledge, especially scientific and technological knowledge, in new strategies for growth. The World Bank has responded with a number of technical assistance and non-lending services through the WBI's Knowledge for Development program. These should be followed by specific lending services in the relevant sectors.
- *Emphasizing a development-oriented approach to improving science and technology in larger middle-income countries.* This involves encouraging the harmonization of the four policy areas detailed extensively in this document.
- *Developing regional S&T-based interventions around specific development problems.* This might be aimed to provide groups of smaller, poorer states with a focused set of strategies to address specific development problems (in health, agriculture, the environment or other areas) around which they could concentrate efforts to improve their capacity, performance, and policies in the S&T sector.[16]

Building the Analytical Base, Promoting Global Public Goods for S&T and Fostering Partnerships. Along with increased operational emphasis on S&T, key areas for new analytical work (AAA) and participation in international fora and activities that will strengthen the knowledge base for S&T in development should be identified and pursued. This would include more work on critical issues such as gathering and

[16] ***Annex 1 of Volume 2*** provides more in-depth coverage of some of the regional interventions specific to the Africa region.

extending the best current knowledge on the phenomenon of migration of scientists, technicians, and other highly skilled individuals from the developing world.[17] The outcomes of this and other AAA work might provide the basis for greater awareness and advocacy on key development issues.

Another important part of an adequate analytical base for S&T in development would entail expansion of the World Bank's participation in international scientific assessments, such as the Millennium Ecosystem Assessment (currently funded in part by the DGF) and the work of the Inter-governmental Panel on Climate Change (IPCC). These scientific assessments, which involve hundreds of experts from all over the world from all stakeholder groups, address issues that are at the heart of the World Bank's work on environment and development. The World Bank should remain involved, both through funding (as is the case with the Millennium Ecosystem Assessment) and through the participation of World Bank staff, when the issues under consideration, like climate change or the conditions of fragile ecosystems, have a clear link and relevance to poverty and development. Other potential areas for involvement include the role of S&T in agricultural productivity and food safety and new technologies that relate to cost-effective delivery of health care services in the developing world.

At the same time, the Thematic Group could explore ways in which the World Bank could play a potentially large and beneficial role in the area of public regulation of science and technology. Whether in public health, bio-safety, agricultural productivity, or related trade and commerce issues, the need for effective public regulatory capacity for S&T-related issues is growing daily, and the capacity of the majority of developing country governments is not keeping pace. The World Bank, using its staff and its partnerships, as well as the Global Distance Learning Network and other WBI outreach products, could facilitate training and capacity building around specific regulatory issues in S&T. These services, if designed correctly, are likely to be in high demand from client governments, which struggle more than ever with new issues in bio-safety and related areas. The World Bank could serve as well as an entry point for complementary policy dialogue and operational activities built around the goal of long-term improvement of S&T capacity.

Finally, on a global level, the Thematic Group could take the lead in facilitating new partnerships and deepening existing ones. One part of such an effort might be on the stimulation of the public-private partnerships that can make development-relevant knowledge available and usable. In the new international context of S&T, private companies now generate an increasing percentage of the new knowledge and technologies available. By keeping the World Bank involved with both public and private entities, poverty issues could be kept on the international research agenda as opposed to being marginalized in the for-profit sector. While it is true that most of the new knowledge generated pertains to rich country markets, much of what is developed is still highly relevant to the problems facing the developing world. The marginal cost of making the new knowledge and research available can be negligible, especially if channels exist to bridge the gaps between producers and users. Private companies have

[17] See Volume Two, p.39.

expressed willingness to share such data when it will be used for public purposes, however, often the channels for distribution and outreach are not there in the private sector. The World Bank should be actively engaged in building partnerships with the private sector to ensure the maximum use and distribution of knowledge and research for the global public good, particularly given the trend toward increasing private ownership of key S&T knowledge.

International partnerships between the World Bank and other multilateral organizations, bilaterals, NGOs and various entities engaged in science and technology for development should also be fostered. The World Bank's ability to catalyze partnerships in S&T would extend to specific organizations, including: bilateral aid agencies concerned with S&T for development (e.g., SAREC, ENRECA, DGIS and NORAD); national scientific foundations, academies, and international science organizations (e.g., the Inter-Academy Council, the Third World Academy of Sciences and the International Council of Scientific Unions,); specialized multilateral organizations (e.g., the OECD and the World Trade Organization); and NGOs and other multilaterals concerned with science (e.g., the Bill and Melinda Gates Foundation, the Rockefeller Foundation, UNESCO, and the World Health Organization).

Anticipated Outcomes…

If the World Bank pursues a more systematic approach to S&T, woven into the regular programs of Networks and Regions through the workings of a well-organized Thematic Group, a decade from now, as we approach the established deadline for reaching the Millennium Development Goals, the World Bank could find itself in a situation in which:

- The responsibility for S&T issues in development is established with a professional Thematic Group that coordinates the growing number of S&T-related activities in the World Bank's work, maximizing the institution's impact.
- Education projects routinely include adequate, culturally appropriate science education components that raise student learning outcomes.
- Middle-income countries have increased the quantity, quality, and relevance of their scientific and technological output in areas that make direct contributions to social and economic goals.
- Low-income countries have targeted human resources development programs that channel talent toward the sectors with the greatest technical needs and that hold the highest opportunity for economic growth and development.
- Infrastructure for research and employment in the sciences has improved throughout the developing world, and subsequently pressure to emigrate has decreased.
- The critical mass of researchers working on development-related problems has increased.
- Access to and transfer of knowledge between producers, wherever they may be, and end-users in firms and public entities, has grown substantially.

- Connections among innovative firms and talented researchers has grown worldwide.
- The critical mass of skilled personnel that developing countries need to implement the Millennium Development Goals is available.

Under such circumstances, the World Bank would help to promote a much fuller contribution of science and technology to the development agenda.

Appendix One:
Sustainably Implementing and Monitoring the
Millennium Development Goals Will Require Improved S&T
Capacity in Client Countries

Millennium Development Goals and the S&T Inputs Necessary for their Attainment	
Target and Indicators	**S&T Response**
Halve between 1990 and 2015, the proportion of people who suffer from hunger • Prevalence of under-weight children (Under five years of age) • Proportion of population below minimum level of dietary energy consumption	Increased agricultural research and enhanced food security regimes
Ensure that by 2015, children everywhere, boys and girls alike, will be able to complete a full course of primary schooling • Net enrollment in primary education • Proportion of pupils starting grade 1 who reach grade 5 • Illiteracy rate of 15-24-year-olds	Improved access to basic education, including science and math education that is built around appropriate curricula and delivered by well-trained teachers
Reduce by two thirds, between 1990 and 2015, the under-five mortality ratio • Under-five mortality rate • Infant mortality rate • Proportion of 1-year-old children immunized against measles	Increased availability of trained medical personnel and improved access to necessary childhood immunizations and nutritional inputs
Reduce by three quarters, between 1990 and 2015, the maternal mortality ratio • Maternal mortality ratio • Proportion of births attended by skilled health personnel	
Have halted by 2015 and begun to reverse the spread of HIV/AIDS • HIV prevalence among 15- to 24-year-old pregnant women • Contraceptive prevalence rate • Number of children orphaned by HIV/AIDS Have halted by 2015 and begun to reverse the incidence of malaria and other major diseases • Prevalence and death rates associated with malaria • Proportion of population in malaria risk areas using the effective malaria prevention and treatment measures • Incidence of tuberculosis (per 100,000 people) • Proportion of tuberculosis cases detected and cured under directly observed treatment short course	Continued research and development into needed vaccines and treatments and improved distribution of available vaccines and treatments for these diseases
Integrate the principles of sustainable development into country policies and programmes and reverse the losses of environmental resources • Proportion of land area covered by forest • Land area protected to maintain biological diversity • GDP per unit of energy use (a proxy for energy efficiency) • Carbon dioxide emissions (per capita) Halve by 2015 the proportion of people without sustainable access to safe drinking water • Proportion of population with sustainable access to an improved water source By 2020 to have achieved a significant improvement in the lives of at least 100 million slum dwellers • Proportion of people with access to improved sanitation	Continued research and development of alternative energy sources and enhanced land-use systems including ground water management techniques, sustainable forestry techniques and improved sanitation systems

Appendix 2: Policy Options by Country Grouping

RAND's country groupings resulted from a composite S&T capacity index of 150 countries created from available indicators of S&T investment, infrastructure and output, including bibliometric literature patterns and interviews with US-based scientists collaborating with scientists internationally	**24 Scientifically Proficient Countries**: Azerbaijan, Belarus, Brazil, Bulgaria, China, Croatia, Cuba, Czech Republic, Estonia, Greece, Hungary, India, Lithuania, Luxembourg, New Zealand, Poland, Portugal, Romania, Singapore, Slovak Republic, Slovenia, South Africa, Spain, Ukraine	**24 Scientifically Developing Countries**: Argentina, Armenia, Benin, Bolivia, Chile, Colombia, Costa Rica, Egypt, Hong Kong, IndonesiaIran, Kuwait, Latvia, Macedonia, Mauritius, Mexico, Moldova, Mongolia, Pakistan, Turkey, Turkmenistan, Uzbekistan, Venezuela, Yugoslavia, FR,	**80 Scientifically Lagging Countries:** Burundi, Central African Rep., Congo, Dem. Rep., Ecuador, Gabon, Georgia Guatemala, Iraq, Jordan, Kazakhstan, Kyrgyz Republic, Malaysia, Nepal, Panama, Peru, Philippines, Saudi Arabia, Sri Lanka, Syrian Arab Rep., Tajikistan, Thailand, Togo, Tunisia, Uganda, United Arab Emirates, Uruguay, Vietnam
Policies for Human Resources Development	**Policies for Primary and Secondary Education** • Further strengthen science curricula in the basic and secondary sciences, ensuring the use of hands-on approaches to teaching, student access to ICTs, etc. • Utilize the results of international student achievement assessments, such as the TIMSS and PISA in the reform and modernization of basic and secondary sciences curricula **Policies for Technical, Scientific and Engineering Education** • Further promote diversification in knowledge delivery between institutes of different types from polytechnics to community colleges, distance education and adult learning centers and open universities • Foment relationships with the private sector to ensure market relevance of skills taught • Ensure equity in access to various types of post-secondary education **Policies for Scientific Research and Graduate Study** • Link the conduct of research and advanced training in the university setting to the productive sector through partnerships with national research laboratories publicly-funded incubators, etc. [See OED 1997] • Articulate a national research agenda to guide the funding, prioritization and advancement of	**Policies for Primary and Secondary Education** • Strengthen science curricula in the basic and secondary sciences, ensuring the use of hands-on approaches to teaching • Provide updated science teacher training • Utilize the results of international student achievement assessments, such as the TIMSS and PISA in the reform and modernization of basic and secondary sciences curricula **Policies for Technical, Scientific and Engineering Education** • Promote diversification in knowledge delivery between institutes of different types from polytechnics to community colleges, distance education and adult learning centers and open universities • Foment relationships with the private sector to ensure market relevance of skills taught **Policies for Scientific Research and Graduate Study** • Encourage the conduct of research and advanced training at home, to create the pool of highly trained specialists needed to access and use available knowledge and begin to advance the frontiers of new knowledge in certain areas of specialization most important for the country's development • Fund, manage and develop regional centers of excellence in specific scientific and engineering disciplines	**Policies for Basic and Secondary Education** • Incorporate basic science education into the primary and secondary level curricula • Provide sufficient training to primary and secondary level teachers so that they are prepared with the skills necessary to teach basic sciences • Benchmark effectiveness of student learning by participating in international assessments (e.g., TIMSS) **Policies for Technical, Scientific and Engineering Education** • Foment relationships with the private sector to ensure relevance of skills taught to market needs • Allow for differentiation of foci between institutions (e.g., institute for specific vocations, automotive schools, etc,) • While ultimately housing high quality universities with strong science and engineering departments is ideal, initially regional centers of excellence with emphasis in specific disciplines may better satisfy the needs of the market given budget constraints **Policies for Scientific Research and Graduate Study** • Focus on creating a few centers of excellence in market-relevant areas of S&T in which the country has a comparative advantage at the regional level

	those specific fields of research with high importance to national development and international competitiveness • Expand grant programs for graduate study and research in disciplines of national interest (e.g., science and engineering) • Encourage conditions in the academic setting conducive to private sector investment in research	• Link academia to the private sector to further relevancy of research and employability of researchers	• Provide grants for scientific research and training abroad coupled with incentive programs to return to minimize brain drain • Link national development priorities to areas of training and research and concentrate financing on building a few strong academic programs in the identified priority disciplines
Policies for Stimulating Demand for Knowledge in the Productive Sector	**Implicit Policies** • Open to trade and foreign direct investment to foster the inflow of knowledge • Allow for further deepening and diversification of credit markets as new types of firms emerge • Strengthen the intellectual property rights regime to provide incentives for innovation, R&D **Explicit Policies** • Increase information on the benefits of R&D through industry-academia linkages, initial subsidies for contract research with universities, student internships with firms, trade fairs and other events to increase exposure to global buyers • Provide tax incentives to firms engaged in R&D and direct support to SMEs • Foster the creation of shared infrastructure and economies of scale for new firms via technology parks and incubators	**Implicit Policies** • Open to trade and foreign direct investment to foster the inflow of knowledge • Allow for the deepening and diversification of credit markets as new types of firms emerge • Establish the framework for an IPR regime to provide incentives for innovation, R&D **Explicit Policies** • Increase information on the benefits of R&D through industry-academia linkages, initial subsidies for contract research with universities, student internships with firms, trade fairs and other events to increase exposure to global buyers • Provide tax incentives to firms engaged in R&D and direct support to SMEs • Foster the creation of shared infrastructure and economies of scale for new firms via technology parks and incubators where appropriate • Establish a framework for the protection of indigenous knowledge	**Implicit Policies** • Establish basic macroeconomic stability, including curbed inflation, strong currency, and proper rates of savings and investment • Open to trade and foreign direct investment to foster the inflow of knowledge • Improve the credit environment for individuals and small businesses **Explicit Policies** • Establish a framework for the protection of indigenous knowledge • Subsidize firm-based training to encourage technology deepening
Policies for Public Support of S&T	**Funding Science** • Leverage benefits from privately performed research conducted through creative public-private partnerships • Provide public support for S&T that is in the public interest and is unlikely to receive sufficient funding from the private sector **Monitoring and Evaluating** • Promote transparency, objectivity and peer review and evaluation procedures in	**Funding Science** • Leverage benefits from privately performed research conducted abroad and at home through creative public-private partnerships • Provide public support for S&T that is in the public interest and is unlikely to receive sufficient funding from the private sector **Monitoring and Evaluating** • Promote transparency, objectivity and peer review and evaluation procedures in determining how to	**Funding Science** • Leverage benefits from privately performed research conducted abroad through creative public-private partnerships • Let the magnitude and urgency of domestic challenges to development establish priorities for the national S&T agenda **Monitoring and Evaluating** • Promote transparency, objectivity and peer review and evaluation procedures in determining

	determining how to award discretionary research funding **Governance and Regulation** • Articulate a national science agenda balanced between various sectors and sub-sectoral S&T interests • Improve governmental regulatory capacity in areas concerning public health, public safety, and other areas relevant to S&T • Ensure equal access to resources for training, funding, and performance across race, gender, etc. • Ensure policy-makers' access to the necessary scientific expertise regarding areas for public debate and decision-making	award discretionary research funding **Governance and Regulation** • Promote high level of openness and public scrutiny and understanding in the sciences • Articulate a national science agenda balanced between leveraging existing knowledge in the sciences and pursuing various areas of national interest and comparative advantage • Improve governmental regulatory capacity in areas concerning public health, public safety, and other areas relevant to S&T • Improve metrology, standards and testing to ensure adherence to international benchmarks for quality • Ensure equal access to resources for training, funding, and performance across race, gender, etc.	how to award discretionary research funding **Governance and Regulation** • Articulate a national science agenda balanced between leveraging existing knowledge in the sciences and pursuing a few areas of national interest and comparative advantage • Prepare for improved governmental regulatory capacity in areas concerning public health, public safety, and other areas relevant to S&T • Prioritize metrology, standards and testing to meet international benchmarks for quality, measurements, etc. • Ensure equal access to resources for training, funding, and performance across race, gender, etc.
Policies for Increasing Access to ICTs	**Policies for ICT Access** • Extend access of available ICTs to a wider range of users **Policies for ICT Use** • Build out hard and soft infrastructures , including Internet and broadband networks • Provide support for the training and education of the human capital base with respect to ICT use, including technical education for the next generation of ICT workers, such as network technicians, computer programmers, web developers and database managers • Educate entrepreneurs and government officials as to how to exploit ICTs so that they may take the lead in developing knowledge economies **Policies for ICT Research** • Support the use of ICTs as pedagogic and research-related tools • Provide incentives for ICT-related R&D • Pursue public-private partnerships in service delivery and research	**Policies for ICT Access** • Extend access of available ICTs to a wider range of users **Policies for ICT Use** • Explore regional solutions to infrastructure creation (both hard and soft information infrastructures) • Provide support for the training and education of the human capital base with respect to ICT use, including technical education for the next generation of ICT workers, such as network technicians, computer programmers, web developers and database managers • Support the use of ICTs as pedagogic tools **Policies for ICT Research** • Pursue public-private partnerships in service delivery and research • Promote research into the efficiency and quality gains potentially achievable in core industries with additional application of ICT	**Policies for ICT Access** • Extend access of available ICTs to a wider range of users • Build out infrastructure to extend coverage **Policies for ICT Use** • Improve regulatory framework to facilitate conducive environment for ICT growth • Provide support for the training and education of the human capital base with respect to ICT use **Policies for ICT Research** • Scientifically lagging countries should generally concern themselves less with ICT-related knowledge creation and more with the challenges related to the expansion of overage, use and access