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Guidelines for Policy-making in Secondary School Science and Technology Education

Guidelines for policy-making in secondary school science and technology education

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Foreword

The policy guidelines presented in this document seek to identify and, where possible, evaluate policy options relating to secondary school science and technology education. They are intended to help ministries of education or others with comparable responsibility to identify, improve, strengthen or develop policies for school science and technology education at the secondary level, although it is recognized that this sector bears significantly different educational responsibilities within different education systems.

Guidelines are not prescriptions for action and, in using them, the following need to be borne in mind:

1. Policy guidelines for school science and technology make sense only when they are interpreted with reference to the cultural norms of, and resources available to, the community that an education system is intended to serve. As a result, some of the guidelines will be more appropriate for some education systems than others. They may also differ in the relative priority to be attached to each of them.
2. No attempt has been made to provide guidelines that are specific to any one education system.
3. It is intended that the guidelines will be used to inform more detailed and system-specific discussions about secondary school science and technology education, many of which are already underway in different parts of the world. The locus and mechanism for such discussions will differ from one education system to another but policy commitments are more likely to be realized in school laboratories, workshops and classrooms if teachers are involved as an integral part of the policy-making process.
4. The presentation of guidelines in this document, given under different headings such as curriculum, assessment or pedagogy, etc., is essentially a matter of convenience. To be effective, any policy for reforming secondary school science or technology education must address the various sets of guidelines in a coherent and integrated way. Individual guidelines must also articulate effectively with relevant aspects of policies for primary science and technology education, e.g. by accommodating a clear strategy for the development of scientific and technological concepts and skills with increasing chronological age.
5. The realization of policy needs to be kept under regular review so that existing guidelines can be revised, or new guidelines introduced, as appropriate.

Introduction

The term 'science or technology education policy' carries more than one meaning. It can be understood in terms of science or technology education designed to support other policy objectives derived from what might be called the policy-making context. For example, science and technology education programmes are commonly seen as broadly supporting policy objectives that are essentially economic, such as improving agricultural and manufacturing practices or workplace skills; social, such as enhancing health care and sanitation; environmental such as maintaining an ecological balance or reducing pollution, or political such as promoting gender or other forms of equity and social justice. These objectives owe their origin to perceived national, local or regional priorities relating to human rights, and to sectors such as agriculture, health, defence, education, energy production and utilization, commerce and manufacturing industry. The policy-making context may also be international, concerned with such matters as peace, ethics and human rights or the inclusion of marginalized groups within society (see, for example, UNESCO/CASTME, 2001).

Despite the obvious relevance of scientific and technological knowledge and expertise to most of these wider policy objectives, school science courses are still often constructed with exclusive reference to the pure disciplines of physics, chemistry and biology rather than to more immediately practical concerns. Such courses are also often regarded as independent of, and as having a higher status than, programmes of technical and technological education.

Science or technology education policy, however, may also be understood as a policy *for* science or technology education, with the relation to wider policy objectives, such as increased agricultural and manufacturing productivity or human development, usually being assumed rather than made explicit. From this perspective, science or technology education policy is concerned with such matters as the science or technology curriculum, the ways in which science or technology may be taught (pedagogy) and assessed, the initial and in-service education of teachers, teacher supply and the provision of laboratories, workshops, equipment, textbooks and other resources. The principal aim is thus the optimum deployment of financial and human capital to raise the quality of science and technology education provided for students at school, this being justified in terms of the benefits to the students themselves, and to the social and economic well-being of the community of which they are a part. It is this optimum deployment that the guidelines in this document seek to promote as a policy for school science and technology education.

Education systems differ in a number of important ways including their history, governance and funding. There are also more subtle but no less profound differences in, for example, the role(s) ascribed to teachers and the assumptions made about what is thought to be good teaching. One result is that what is seen as progressive teaching within one culture can be regarded as regressive when viewed from the perspective of another.

Given this diversity, it is difficult to offer a set of general policy prescriptions to raise the standards of work achieved by students in schools within different education systems. However, the problem of policy guidance becomes tractable if a number of constraints are imposed. By confining attention to secondary school science and, to a lesser extent, technology, attention can be focused on components of the school curriculum that are common to all education systems and directed towards the broadly common aim of promoting scientific and technological literacy. Such focusing is also helped by the international nature of the scientific enterprise and by the universal acknowledgement of the importance of scientific and technological knowledge and expertise to the realization of a range of personal, social and economic goals and the education of an adequate supply of professionally qualified scientists and technologists.

Policy-making and policy realization

Policies, however carefully constructed and financed, have little significance if they are not implemented. Perhaps for this reason, much of the literature relating to educational policy rests upon a distinction between policy 'making' and policy 'implementation'. Typically, governments are seen as making educational policy at a national, regional or local level, and responsibility for its implementation is then assumed to lie elsewhere, usually with teachers or school managers. Such a distinction has a number of important consequences. It allows those responsible for implementing policy to be charged with distorting or even subverting the intentions of policy-makers when these intentions fail to materialize in classrooms or laboratories. It also casts teachers in the role either of passive recipients of policy, or of mere practitioners responsible for policy implementation but excluded from the policy-making process. At a more theoretical level, it draws a distinction between knowledge and action that is often impossible to sustain in the context of teachers' professional practice.

An alternative approach to understanding educational policy asserts that such policy is made at a variety of levels within education systems and by a variety of agencies and individuals. From this perspective, policy-making is a set of complex and subtle negotiations and the distinction between policy 'making' and policy 'implementation' largely collapses in favour of the notion of policy 'realization'. Thus, science teachers, required by national, regional or other government to adopt, for example, a more investigative approach to science teaching will interpret the requirements, however detailed, in terms of their own circumstances and professional experience. That experience is necessarily shaped by a range of personal, social and cultural assumptions about matters as diverse as the function of schooling, the maintenance of classroom discipline, the educational function of science, and the constraints of time and resources that govern science teachers' daily work. More direct influences may include the demands of external accountability and inspection, including public examinations and the expectations of parents which, in many education systems, are markedly different for boys and girls.

In considering the guidelines in this document, it is essential, therefore, to acknowledge and accommodate the creative role of teachers in effecting change. Changing what teachers of science or technology do in their classrooms, laboratories and workshops involves changing values as well as curriculum content, teaching methods or assessment procedures. Those values are inherent in both the old and the new practice, and the old will not be discarded out of hand. Change thus requires time and opportunity for dialogue when the meaning, significance and advantages of doing something differently can be negotiated.

This is the case whatever the formal structure[1] of the decision-making process within an educational system, since that process has a direct effect on the manner in which decisions are understood, accepted and adopted by all those concerned.

Two other introductory comments are appropriate. First, science and technology teachers do not work in isolation but within schools and education systems. As with teachers of other subjects, they are likely to be most effective when working in successful schools. The research that has been done (Sammons et al., 1995) into effective schools suggests that such schools are characterized by: (a) professional leadership which is firm and purposeful; (b) a clear and shared sense of purpose supported by consistency of practice and a collegial manner of working; (c) an orderly and attractive learning environment; (d) an emphasis upon the central goals of teaching and learning with a focus on achievement; (e) high and widely shared expectations on the part of both teachers and students; (f) firm and fair discipline that acknowledges students' sense of worth and esteem; (g) careful monitoring of students' progress with positive feedback; (h) close parental involvement in students' work; and (i) a commitment to ongoing school-based staff development.

Secondly, it is important to acknowledge that the distinctions drawn in this document between, for example, curriculum, pedagogy and assessment are essentially a convenient way of presenting a range of policy options. In practice, how science or technology is taught is strongly influenced by what has to be taught, by what is assessed, by the resources available, by the teacher's own academic and professional background, and by wider cultural and social norms. It follows that any policy for reforming school science and technology must address these various elements in a coherent and integrated way. If the learning outcomes promoted by the science or technology curriculum are to be realized, they must be identified in terms that allow them to be promoted explicitly by programmes of initial and in-service teacher education, incorporated within programmes of summative and formative assessment, and integrated within systems of accountability, monitoring or inspection. In other words, the various components of a science and technology education policy must be mutually supportive and directed towards common goals.

In this context, it is helpful to recognize that distinctions can be drawn between a specified or *intended* curriculum, the *implemented* curriculum and the *attained* curriculum. The differences between these can be substantial. Changing an intended curriculum is relatively straightforward and is often equated with revising science and technology syllabuses with, or without, revising the examinations set upon them. Reforming the implemented curriculum, however, is a much more complex task, the outcomes of which are difficult to predict. The principal reason for this was indicated above, namely that when required to change their working practices, teachers interpret the new demands being made upon them in the light of their experience and their individual professional circumstances, including the resources available to them. These differ from school to school and from teacher to teacher. Teachers have good reasons, not always made explicit, for doing what they do and, if they are to change, they will need to value the advantage and practicality of doing so.

1. It should be noted that in recent years there have been profound changes in that structure in many countries, although the changes follow no single pattern. In some cases, the need to respond to powerful regional sentiments has led to a significant decentralization of national government responsibility for educational matters. In others, local and municipal authorities have sometimes gained and sometimes lost responsibility for education, at the expense of national government. For an overview of fourteen OECD countries, see CERI, 1995.

Policy guidelines

- *The relationship between science and technology education policy and practice is best understood in terms of policy realization rather than policy implementation.*
- *Science and technology education policy will be more effective if it forms part of a wider policy directed towards improving schools as a whole.*
- *Any policy for reforming school science and technology education must address all the elements of professional practice in a coherent and integrated way, including the curriculum, pedagogy, assessment, material resources, and the initial and ongoing education of teachers.*

Organizing a policy planning process

As noted above, policy for secondary school science or technology education is determined within a wider policy framework that is established by national, state, regional and/or local government and sometimes includes reference to international priorities. This wider educational policy framework accommodates issues that range from the age of compulsory schooling through teacher supply to finance, and it articulates with elements of other government policies that are essentially social or economic and concerned with such matters as health, environmental sustainability, agriculture and employment.

Determining policy for school science and technology education within this wider context requires a mechanism that can access the various agencies and organizations with a legitimate interest in these components of the school curriculum. These agencies and organizations will differ somewhat between education systems, partly for historical reasons. The most common partners include government, its advisers/inspectors, the professional scientific and technological communities, employers, relevant teachers' organizations, institutions of higher education, and researchers in science and technology education (especially those with expertise in children's conceptual development and progression). Parents, students and many other individuals or organizations (e.g. textbook publishers, examination boards) may also be involved, usually at the stage when proposals are available for consultation and comment.

The precise means by which these various agencies are enabled to focus their attention on school science and technology education will differ from one education system to another. In some cases, the form and content of school science and technology education are the direct responsibility of the ministry of education or its equivalent. In others, such responsibility lies with a quasi-governmental organization, with terms of reference and category of membership established by legislation or other means. In yet others, ad hoc groups are set up that report to government and are then discharged.

Policy guidelines

Whatever the means of establishing policy for school science and technology education, it is essential that the mechanism:

- *Allows for the input of other policies relating to the school curriculum and to other government objectives that are principally social or economic rather than educational.*
- *Represents the interests of those whose work is likely to be substantially affected by the changes under consideration and commands their confidence.*

- *Encourages the formulation of clear attainable and costed goals, the implementation of which can be monitored in accordance with an agreed schedule.*
- *Reflects the conditions under which science and technology teachers work or may realistically be expected to work in schools.*
- *Requires wide consultation before final decisions are reached and allows science and technology teachers an active role in the planning process.*
- *Allows for ongoing revision in the light of experience, and developments in science, technology and educational theory and practice.*

Specifying the goals: science

Specifying the goals of a school science or technology curriculum involves making a series of choices about what it is thought desirable that students should learn by studying science or technology respectively. Such choices reflect the wider purposes that school science and technology courses are intended to serve. They are invariably the result of compromises of various kinds and they reflect the assumptions and values of those who make them. In addition to meeting the educational needs and aspirations of the students, such goals have to accommodate national, regional or local priorities, a range of social or environmental concerns, and the demands of industry and other sectors of employment. As a result, specifying curriculum goals is a highly contested and political process.

Since it is possible to make a variety of different choices, it is equally possible to envisage a range of school science or technology courses that differ in the emphasis given to particular topics or approaches. Some courses might place an emphasis upon social, personal or environmental concerns, or upon a range of science, technology and society (STS) issues. Others may stress the importance of laboratory investigations conducted by students to develop their scientific skills, or focus attention upon the learning of fundamental scientific principles and concepts. Some may seek to present science and technology as distinct but related subjects while others reflect a conviction that these subjects are essentially artificial constructions and are thus best taught as an integrated programme. Different choices are often appropriate at the primary and secondary levels of education and in different education systems.

Currently, there is some measure of agreement that school science and technology should be concerned with promoting scientific and technological literacy (STL) for all. The Project 2000+ Declaration,[2] for example, asserts that priority should be assigned to the development and introduction of programmes leading to scientific and technological literacy for all in all the countries of the world (UNESCO, 1994). The interpretation to be given to scientific and technological literacy will differ from one education system to another. In those education systems within which participation in secondary education is very low, responsibility for promoting scientific and technological literacy will fall principally upon the primary sector.

One widely perceived important consequence of this declaration is that schools should require students to follow a broad and balanced study of science during compulsory schooling. Experience suggests that without such a requirement, girls often abandon the study of science

2. The declaration was the work of a Steering Committee drawn from UNESCO, the World Bank, UNICEF, UNDP, UNEP, the Commonwealth Secretariat, the International Council of Scientific Unions (ICSU), the International Council of Associations for Science Education (ICASE), the International Organization for Science and Technology Education (IOSTE), Gender and Science and Technology (GASAT) and the World Council of Associations for Technology Education (WOCATE).

at the first opportunity, or restrict their scientific studies to the biological sciences or to a narrower applied field such as health education. Scientific literacy is seen as essential in: (a) laying the foundations of a wider public understanding of science and technology; (b) enabling individuals to function effectively in an increasingly scientific and technological world, including in relation to their health, well-being and employment; (c) educating the workforce necessary for economic and social development; and (d) informing decision-makers, especially in industry and government where few, if any, major issues do not have a scientific or a technical aspect.

'Educating the workforce' is to be understood as including the education of those who will become professional scientists. Reconciling the demands of 'science for all' with the more specialized needs of these future professionals is not a straightforward task and most education systems struggle to achieve an appropriate accommodation. Indeed, scientific literacy for all remains more of an aspiration than a reality. The challenge can be seen as one of constructing programmes of 'science for all' in the lower levels of education that will meet the needs of most students while laying the foundations of the more discipline-oriented approach required by the smaller number who will subsequently specialize in the sciences. The point at which the shift is made in curriculum emphasis from a general to a more specialized science education will depend on a number of factors, including the participation rates in secondary and higher education. In some education systems, scientific and technological literacy can best be understood in terms of the contribution that science and technology can make to pressing personal social and economic needs, e.g. those concerning health, the prevention of disease, sanitation, improved agricultural practices and the supply of clean water.

The manner in which broad aims are translated into curriculum goals necessarily differs from one education system to another. Again, however, there is a broad measure of agreement[3] that school science should stimulate students' curiosity and imagination and enable them to: (a) acquire knowledge and understanding of the important scientific ideas and explanatory frameworks that relate to their everyday experiences and needs; (b) understand how scientific inquiry is conducted and appreciate the reasoning and kinds of evidence that underpin scientific knowledge claims; (c) appreciate the role that science plays in the modern world; (d) feel confident in discussing a range of personal, social and other issues that have a scientific dimension; and (e) develop the skills and attitudes necessary to help them contribute to sustainable social and economic development.

School technology might be defined as drawing upon knowledge and practical skills to plan, design, improve or make and evaluate an artefact, process or system in order to achieve some practical purpose. The knowledge to be called upon is not exclusively scientific and the practical purpose may be personal, social or economic/commercial and be related to almost any field of human concern from health, sanitation and medicine to agriculture, transport and information technology.

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3. The Third International Mathematics and Science Study (TIMSS) offers an interesting perspective on the science curricula of the countries participating in the project. Using data drawn from three different types of source in thirty-seven countries (statements of content standards, school science textbooks and teachers), Cogan and Schmidt (2001) explored the idea of a 'world core' curriculum for eighth-grade students. Defining a 'world core' curriculum as: '. . . those topics appearing in 70 per cent of countries' textbooks, content standards, and taught by at least 70 per cent of teachers in at least 70 per cent of countries', they concluded that no single scientific topic met this criterion. If, however, the core were defined solely in terms of content standards and textbooks, then it embraced twenty-six topics. In addition, there was some diversity in the emphasis placed upon individual topics in the textbooks and content standards as well as in the emphasis and time given to them by the science teachers. 'Chemical properties', for example, featured prominently in many textbooks but the topic was given much less emphasis either by teachers or in content standards.

As with school science education, it is possible to specify a series of goals for a school technology curriculum, and it is likely that there will be some overlap between them. Typically, these goals might include enabling students to: (a) develop, plan and communicate ideas; (b) work with tools, equipment, materials and components to produce quality products; (c) evaluate processes and products; (d) acquire a knowledge and understanding of materials and components; (e) acquire a knowledge of technological systems and control mechanisms; (f) understand the contribution that technology can make to sustainable personal, social and economic development; (g) understand the power that different technologies can give to, or remove from, different groups of people; and (h) develop an understanding of, and acquire the skills needed to improve, indigenous technological activities.

The ways in which these goals for science and technology education are translated into curriculum materials and practices depend on a number of factors, including the age of the students, and it will differ from one education system to another. In some education systems, factors such as the overlap between some of the goals of school science and technology education, the ways in which science and technology are interrelated in the modern world, and the competence/shortage of teachers have led to the development of integrated courses of science and technology education, although not necessarily at both primary and secondary level. In others, science and technology are distinct curriculum components, although co-ordination and collaboration are regarded as important. In all cases, however, scientific and technological literacy is to be understood in relation to local culture and values, to the social and economic needs and aspirations of each country and its peoples, and to the wider general aims of education that promote the all-round development of the student and sustain human rights and basic freedoms.

There will also be differences between education systems in the way in which the agreed curriculum is to be communicated to the teachers who will be responsible for 'delivering' it. It is possible to construct a curriculum principally in terms of intended learning outcomes as, for example, in the case of the South African school science curriculum. Here, the emphasis is on the skills, abilities and attitudes to be acquired, rather than on the body of knowledge to be learnt.[4] Other curricula continue to be specified mainly in terms of content, allied with indications of the way in which the content is to be presented to students at various stages of formal schooling. For example, while younger students might be expected to learn that light travels in straight lines and can be reflected from a polished surface, their older counterparts might be taught about light as a component of the electromagnetic spectrum and about the reflection, refraction and diffraction of waves.

Scientific knowledge and local knowledge

Since the fundamental laws and principles of science are of general validity, scientific knowledge is often said to be value-free and have a universal quality. It has also traditionally been seen as public knowledge, subject to public testing and, once validated, freely available. In recent years, however, different claims about the nature, authority and accessibility of scientific knowledge have emerged and gained some currency. The powerful theories of science are sometimes characterized as 'Western' and neglectful of other, more local ways of understanding natural phenomena. Such 'Western' science is sometimes presented as a form of neo-colonialism on the part of the more prosperous industrialized nations.

4. Recent amendments to the South African national curriculum statements have raised the profile of the knowledge that students are required to learn, although the commitment to outcomes based on education remains.

In contrast to the universality of science, many traditional technologies are based upon local knowledge, skill and materials. This local knowledge is often of major economic importance. It is also often highly sophisticated, e.g. the knowledge underpinning the systems of navigation used by the native peoples of Australia, although it is rarely written down. In addition, such knowledge is acquired by experience and informal education and is often not transferable to other contexts or cultures. In essence, it is knowledge valued and sustained for action rather than knowledge acquired for its own sake.

It is important that local technologies and the various forms of understanding of, and operation within, the natural world, are both acknowledged and valued. There is no shortage of examples of how local technologies can be used to illustrate underlying scientific and/or technological principles (Knamiller, 1984; Swift, 1992).

It is equally important to recognize that students' existing understanding of, and beliefs about, the world in which they live must be taken into account if those beliefs are to be supplemented or even replaced by other, more conventionally scientific insights into, and beliefs about, a range of natural phenomena. Many scientific concepts contrast sharply with everyday 'common-sense' understandings of natural phenomena, a feature that is common to all societies and not simply those that have inherited directly the Western European tradition of scientific development. This 'uncommonsense' of science can be an obstacle to learning science and it is important that teachers be familiar with the 'everyday understandings' of their students, and with strategies for helping them to develop more orthodox scientific ideas.

As far as school science and technology curricula are concerned, therefore, it is important to acknowledge that there are diverse ways of explaining the material world and that these shape the ideas that students bring to their science lessons. Equally, however, it is the principal task of school science education to help students develop an understanding of the basic concepts and theories of modern science, together with an insight into how these are established and the confidence that can be placed in them.

A particularly lively debate concerns the notion of 'indigenous sciences' with some commentators, for example, arguing for 'African science' as something distinct from Western or European science. The debate is confused, not least because it has both a political and an epistemological dimension, and its resolution for education is significant. However, without entering into the debate, it is possible to agree with Pomeroy (1994) that: (a) students will be more likely to see science as a less alien pursuit if they can situate it in the context of their lives; (b) the approach to teaching science education must match the learning styles of the students; (c) teachers' expectations are significant determinants of students' performance; (d) some science texts historically have ignored the contributions of women, Africans, Asians, etc.; (e) the world view of Western science is linear, reductionist, causal and bipolar • students coming to class with other world views (e.g. organic, yin and yang, theological and triadic) often require help to relate to language and ideas rooted in other worldviews; (f) students will relate more easily to science if the inquiry is related to their own cultural knowledge and they will have a greater pride in their own cultures if they understand the scientific principles at work in local practices.

Policy guidelines

The goals of school science education should:

- *Be directed towards the promotion of the scientific literacy of all students and laying the foundations for a wider public understanding of science. Such literacy is to be understood in relation to local culture and values and to the wider personal, social and economic needs that the education system is designed to promote, and as embracing the more specialized education required of future science specialists. It* *may be necessary to decide at what point to introduce a shift from a general curriculum emphasis to a more specialized science education.*

- *Seek to provide a broad and balanced science education for all students throughout compulsory schooling that offers students an opportunity to acquire scientific knowledge and understanding, to learn how scientific research is conducted, and to appreciate how science relates to their everyday lives and concerns.*
- *Be designed to accommodate measurable progression in what students are required to learn and to do, so that different goals are appropriate at different ages.*
- *Be developed within a framework that allows for ongoing revision in the light of, for example, new scientific knowledge, pedagogies or insights into how students learn.*
- *Be responsive to perceived national needs, (such as shelter, transport, energy, health, agriculture, sustainability, and economic and social development).*
- *State clearly what teachers are expected to teach and students are expected to learn and be able to do at each stage of compulsory schooling.*
- *Be specified in ways that leave room for teachers to exercise initiative and respond to the needs of those whom they teach and the locality within which they work.*
- *Take full account of students' local knowledge and the understanding of natural phenomena that they bring to their science lessons*
- *Relate, in clearly understood and articulated ways, to the goals of technology education, where science and technology are not taught as a single curriculum component.*

Specifying the goals: technology

The nature of science and of technology and their interrelationships have been much studied by scholars. Three broad conclusions can be drawn from this work. First, there are important differences between scientific and technological activity. Secondly, categorizing technology simply as ‘applied science’ is misleading and devalues the distinctive and creative dimension of practical technological activity. Thirdly, the nature of the interaction of science and technology depends on a range of social and historical factors as well as upon the nature of the technology itself.

As far as school science and technology courses are concerned, these have often developed independently of each other. In some education systems, they constitute discrete components of the school timetable and are ascribed, not necessarily explicitly, a different status, that of technology commonly being lower than that of so-called ‘pure’ science. Yet it is clear that science and technology teachers have much to gain from working more closely together. Some science teachers have long used technological artefacts to provide motivation and relevance in science lessons, and an understanding of relevant scientific principles is often essential to effective designing and making.

Science and technology teachers working more closely together may involve co-ordination or collaboration (Barlex and Pitt, 2000). The teachers of the two subjects may plan their work with a sensitivity to each other’s needs, for example by establishing a common terminology, deploying the same analogies and sequencing the teaching of scientific concepts to optimum mutual advantage. Work of this kind can then be developed into more collaborative activities in which teachers of science and technology jointly plan elements of their courses. Those elements will allow students to experience for themselves the interaction of scientific/theoretical and technological/practical knowledge and help them develop their skills in both areas.

A somewhat different approach involves the development of courses in ‘techno-science’ that treat science and technology as equals. Although there have been attempts to develop courses of this kind (e.g. Bencze, 2001), they so far remain somewhat isolated efforts, especially at the secondary education level.

For most students, however, distinctions between science and technology can seem both arbitrary and unhelpful. In addition, technology education allied with school science ‘gathers together under one legitimate umbrella . . . health education, home-economics, population, craft, energy and . . . environmental education. . . . In a word, technology education is relevant education’ (Knamiller, 1984, p. 64). It can fit readily into national development goals and priorities, as well as help to meet the personal, social and intellectual needs of the students. Every society has developed its own indigenous technologies relating, for example, to food preparation and preservation, metalworking, fishing and agriculture and house-building. At the school level, scientific and technological education (STE) can draw upon these and other technologies to illustrate the underlying scientific principles and to develop students' scientific skills and technological competence and, thereby, pave the way for technological change. An important consequence of this approach, however, is that courses of STE will be more diverse than is usually the case with school science where the emphasis is all too often upon the learning of general principles divorced from any particular context. In many education systems, the case for teaching science and technology as an integrated course is strong, especially at the primary level. Sometimes these take the form of science-based technology courses in which scientific knowledge and principles are presented in practical contexts, e.g. household electricity, healthy eating and disease prevention. In other cases, courses might be best described as technology-based science courses. Here, the technological context of personal and social relevance is used as the basis for understanding selected scientific concepts. A somewhat different type of course, so-called STS programmes, emphasizes the relationships of science and technology to the wider cultural context. Some of the broader issues associated with the integration of the sciences, and of science with technology, are considered in the next chapter.

Policy guidelines

The goals of school technology education should:

- *Promote technological literacy as a component of the general education of all students. Such literacy is to be understood in relation to local culture and values and to the wider personal, social and economic needs that the education system is designed to promote.*
- *Be responsive to local, regional or national technological materials, resources and values.*
- *Be designed to accommodate measurable progression in what students are required to learn and to do, so that different goals are appropriate at different ages.*
- *State clearly what teachers are expected to teach and what students are expected to learn, and be able to do this at each stage of compulsory schooling.*
- *Reflect a view of technology as a set of creative processes involving hand and mind that lead to the design, production and evaluation of high-quality artefacts and systems*
- *Lead to courses that enable students to become confident in designing and making, using a variety of tools, equipment, materials and strategies.*
- *Relate in clearly understood and articulated ways to the goals of science education, where science and technology and science are not taught as a single curriculum component.*
- *Be developed within a framework that allows for ongoing revision in the light of, for example, the emergence of new technologies, pedagogies or insights into how students learn.*

Curriculum planning

Most education systems have developed mechanisms for curriculum planning and development. The nature of these mechanisms depends upon a number of factors, notably the relative importance of the roles of central or other government in the planning and development process and that of other agencies, organizations and individuals, including teachers. In recent years, a number of education systems have introduced or revised statutory curricula, although the manner in which such curricula are specified differs from one system to another. Such reform also reflects several different factors. These include a concern to ensure an appropriate curriculum entitlement for all students, a perceived need to raise the standards of student achievement, a demand for greater accountability within an education system, and an enhanced recognition of the importance of schooling to personal, social, local or national priorities and to international economic competitiveness.

The main issues involved in curriculum planning in school science and technology (e.g. curriculum options, language, gender, assessment) form the substance of this document and thus need not be elaborated here. It is possible, however, to offer the following guidelines.

Policy guidelines

- *Mechanisms for curriculum construction and reform that are transparent and command the support of all those involved with a legitimate interest in school science and technology education need to be developed.*
- *Those mechanisms must be capable of generating an initial agreement about the objectives of science and technology education at the primary, lower secondary and upper secondary levels.*
- *Reform of school science and technology curricula must be seen as part of a larger process that includes reform of the systems of assessment and the initial and ongoing education of teachers, and the provision of the necessary financial and material resources.*
- *Curriculum aims and objectives must be specified in terms that allow the extent to which these are achieved to be monitored on a regular basis so that, if necessary, appropriate adjustments can be made.*
- *A wide range of different 'performance indicators' should be developed for curriculum evaluation.*
- *Any mechanism for curriculum planning must be sufficiently flexible to respond to changes in the demands on schools as well as to changes in science itself.*

- *Curriculum planning must take due account of what is known about how students learn, how their understanding of natural phenomena develops with age, and how they can be most effectively taught.*
- *Planning of the school science and technology curriculum must be compatible with the curriculum followed by those training to be teachers.*
- *Curriculum planning must be sensitive to a wide-range of planning indicators, including the nature and extent of the teaching, material and other resources available. It must also provide for the ongoing professional development of science and technology teachers.*
- *Curriculum planning must be an integral part of a wider planning process that reflects national, regional or local development or other priorities.*
- *Resources must be made available to support an ongoing programme of research that identifies and evaluates priorities for development. For example, is the writing of new curriculum materials to be prioritized over other policy options?*
- *The strategy for, and financial implications of, introducing new science and technology curricula must be an integral part of the curriculum planning process.*
- *School science and technology courses must be planned as part of an overall curriculum so that, for example, students acquire the mathematical knowledge and skills needed to progress with their scientific and technological studies.*

Science courses: integrated or individual?

In many countries, there has been, and remains, a debate about the relative merits of teaching science in the lower secondary school as an integrated or combined course rather than as two or three separate subjects taught sequentially or concurrently. The most common patterns in countries with an Anglophone tradition in education incorporate single 'integrated' curricula that draw on the three major scientific disciplines of physics, chemistry and biology, but increasingly also include elements of earth science, agricultural science, and the health and environmental sciences. Integrated courses of this kind encourage links between the basic scientific disciplines and a range of environmental, health and other issues, and they offer the opportunity to simplify textbook provision, staffing, timetabling, laboratory provision and examining procedures. They thus offer significant advantages to students, teachers and education planners and policy-makers.

However, they place considerable demands on teachers and require appropriate programmes of teacher education. There is no evidence to suggest that an integrated approach to science education at this level leads to less satisfactory student learning outcomes than courses based upon the individual scientific disciplines. An important issue for policy-makers, therefore, is likely to be that of cost.

Cost is also likely to be an important issue since, all other things being equal, costs will be less if the number of scientific disciplines taught is reduced. A case for such reduction can be made on the grounds that there is a substantial overlap in the scientific skills promoted by courses in the basic sciences and that, in many contexts, science curricula are overloaded with factual content that could be reduced without significant loss. It is, of course, important to acknowledge the higher status commonly accorded to teaching the individual scientific disciplines, the commitment of some teachers to only one of these disciplines and the mis-match that sometimes occurs between the needs of the schools and the nature of the graduate output from higher education. In the later secondary years in most education systems, the basic scientific disciplines continue to be taught as separate subjects, not least to meet the demands for entry into higher education.

Integration can take a number of different forms but courses need to be interdisciplinary or transdisciplinary and not simply a collection of topics drawn from the traditional basic science courses. Integrated courses are more common at the lower, rather than the upper, secondary level. They may be integrated by means of topics (e.g. water), concepts (e.g. energy), processes (e.g. investigative skills) or themes (e.g. the environment), although these organizing principles are often so interwoven that any simple classification of integrated courses is not possible (Haggis and Adey, 1979). In addition, integrated science courses can be 'delivered' in different ways, including being taught by several contributing teachers. In many education systems, responsibility for teaching an integrated science course in the lower secondary school will lie with one teacher.

The principal questions for policy-makers would seem to be as follows.

1. What are the learning outcomes used to justify the individual scientific disciplines rather than an integrated course?
2. Can these learning outcomes be achieved by carefully devised programmes of integrated science?
3. How, and to what extent, can the additional costs of individual science curriculum options be justified?
4. How well prepared to teach integrated courses at school level are those graduating in science from institutions of higher education or qualifying as teachers from teacher training colleges?
5. To what extent, and in what ways, is a commitment to integrated science reflected in school science textbooks and other curriculum materials?

Most integrated science courses have been developed locally in the country or region in which they are to be used, although they may owe some of their basic ideas to courses constructed elsewhere. They tend to emphasize observation, inquiry and first-hand experience, commonly draw upon the local environment, and use simple, low-cost apparatus and equipment. The integration usually embraces both science and technology but other elements may be accommodated and even form the focus of a large part of the work, e.g. health education, nutrition, environmental issues and sustainable development. Attempts may also be made to integrate courses of this kind with other components of the curriculum, including mathematics. Integrated courses of study that are well-constructed allow students to see the relevance of their studies to their everyday lives, experiences and needs and allows the curriculum to respond more flexibly to national, regional or local priorities, especially if that curriculum has a modular structure. It is important, however, that in any form of integration, the distinctive contributions that science and technology can make to the education of students are not lost.

Policy guidelines

- *Integrated courses of science should be promoted at the lower secondary level, since they have significant educational and cost advantages.*
- *Integrated courses in science should have a clear interdisciplinary or transdisciplinary structure and not consist simply of topics drawn from the basic sciences. Integration may be by topic, concept, process or theme.*
- *In the developing world, the needs of most students are likely to be best met by courses that integrate science and technology.*
- *Teachers need to be trained to teach integrated courses and be provided with suitable resources and ongoing in-service support.*

Curriculum materials

Curriculum materials are of various kinds. They include textbooks, workbooks, examination guides, worksheets, teachers' guides and library resources. Among these materials, there is considerable variation in quality and relevance. There are also differences between education systems in the extent to which curriculum materials are available and in the ways in which they are used. In most developing countries, for example, curriculum materials for use in secondary schools are not provided free of charge to students. Likewise, in some systems, official curriculum materials are much less used by students than 'unofficial' commercially produced examination guides or workbooks. While this may be a matter of relative cost, this is not always the case.

The relative importance attached by students and teachers to curriculum materials, notably textbooks, varies from one education system to another. In the developing world, textbooks are often seen as symbols not simply of schooling but also of modernity and they lie at the heart of the education process. Where there is an acute shortage of teachers, and other resources are scarce, textbooks can become the repository of school knowledge and act as a de facto prescribed curriculum.

The importance of curriculum materials has been highlighted by a World Bank study that indicated that, once schools are in place, incremental expenditure on curriculum, textbooks and other inputs is a more significant factor in promoting students' learning than incremental investment in physical infrastructure (Herz et al., 1991). Other research has shown that the availability of books is consistently positively associated with higher levels of student achievement (Crossley and Murby, 1994).

The variation in the quality, relevance and availability of curriculum materials among education systems, and the costs associated with their production, suggest a number of policy options, as follows.

Policy guidelines

- *The writing of new curriculum materials must be weighed alongside other possible strategies for effecting change (e.g. in-service courses for teachers) and appropriate priorities determined.*
- *Once schools are in place, incremental investment in textbooks and other curriculum materials should be prioritized over incremental investment in physical infrastructure since the former is more likely to lead to higher levels of student achievement.*
- *Clear strategies need to be developed for writing, testing and disseminating new curriculum materials, and their effectiveness kept under review.*

- *Where the quality of existing curriculum materials is high, attention should be focused on their dissemination and effective use. Where the quality is poor, curriculum development should be given a priority.*
- *Where 'unofficial' curriculum materials are more widely used than official curriculum guides, the reasons for this greater popularity need to be established and, where appropriate, official curriculum materials revised accordingly.*
- *Where the range of available curriculum materials is very narrow (e.g. restricted to textbooks), resources need to be made available to extend this range to include, for example, teachers' guides, charts, workbooks and library books. Consideration should be given to sharing the costs by, for example, regional or other forms of co-publication and/or by industrial or commercial sponsorship.*
- *Where the range of available curriculum materials is very wide, attention needs to be given to such issues as coherence, duplication and the appropriate allocation of resources. It may be helpful for a curriculum development agency to identify a core of essential scientific and technological knowledge and understanding to be required of all students.*
- *Curriculum materials developed for one education system are rarely suitable for another without considerable adaptation. Where adoption of this kind is a possibility, attention needs to be given both to the relative costs of adaptation and of writing local curriculum materials* ab initio *and to the importance and value of developing or maintaining an indigenous curriculum development capacity.*

Preparing curriculum materials

It is not possible to consider the writing or re-writing of curriculum materials without giving attention to how they are likely to be used by the teachers or students for whom they are intended. Every education system has experience of producing seemingly high quality curriculum materials that have failed to capture the commitment of the teachers in the schools. Likewise, in some education systems, officially produced and promoted curriculum materials have much less appeal to students and their teachers than the various examination and tuition guides that constitute a large and successful alternative publishing market.

The writing, publishing and dissemination of curriculum materials is a task that requires a range of skills that extend beyond the construction of text to include an understanding of how children learn and a range of issues relating to language, design, format, cost and marketing. The writing of curriculum materials is thus often a collaborative process in which these various elements form an integrated whole.

Writing of primary school mathematics in India, Harris (1999, p. 31) has noted that textbooks 'present models of people, models of behaviour and models of thought patterns'. There is little doubt that this judgement can be extended to secondary school science and technology and to other countries. Those who write (and those who use) textbooks and other curriculum materials therefore need to recognize the 'hidden curriculum' presented by publications of this kind and to be particularly sensitive to issues relating to gender equity, language and culture. Much has been learnt in recent years about the subtlety, extent and influence of these issues within different cultures. Some inequitable features are indigenous, e.g. the emphasis on masculine roles and behaviour in nursery or other rhymes. Others are imported, e.g. the disparity between the home lives of many female students in the developing world and the images presented to them in textbooks produced and published elsewhere.

The costs of preparing, evaluating and publishing new and high-quality curriculum materials is inevitably high. Nonetheless, as noted above, curriculum materials have a key role to play both in promoting student learning and improving teachers' professional practice.

Well-designed teachers' guides, for example, may be a more effective way than short, occasional in-service courses of introducing teachers to new ideas about science or technology teaching, although they should be regarded as a necessary, rather than a sufficient, factor in bringing about change.

Policy guidelines

The writing of new curriculum materials must:

- *Be a collaborative effort; those involved are likely to include subject-matter experts, science/technology teachers and researchers familiar with how children's scientific and technological understanding develops with age.*
- *Promote gender, racial and other forms of equity and accommodate cultural and linguistic diversity.*
- *Involve from the outset those who will be responsible for the format, design and dissemination of the final curriculum material(s).*
- *Involve trial and evaluation in the schools in which the materials will eventually be used.*

Teaching methods

The history of science education is replete with references to different approaches to teaching school science, with terms such as ‘teaching by investigation’, ‘project work’ and ‘rote learning’ being commonplace. The extent to which such terms are an accurate reflection of what science teachers actually do when teaching their subject in schools is, of course, highly problematic. The same history also shows that these different approaches to teaching science have been justified by reference to different theories about how children learn, although, once again, the extent to which teachers themselves have been familiar with these theories can be questioned. The various pedagogies have also been supported by broader cultural assumptions about the role of the teacher. In some cultures, teachers have been seen as sources of knowledge, expertise and authority that cannot be questioned. Such a perspective does not always sit comfortably alongside the interrogative nature of the scientific enterprise. In other cultures, the authority of teachers has been challenged, with a consequent decline in their standing in the eyes not only of their students but of the wider community.

The history of school technology education is much more recent than that of school science education. Its origins lie in a diversity of manual, craft and art and design programmes, many of which have had a lower status than more academic courses. Within the last decade or so, many education systems have invested heavily in the development of technology as a curriculum component that is distinct and worthy of an established place in general education. Given this recent history, teaching methods are still in something of a state of flux but there is agreement that students must be taught the skills that will allow them to engage in planning, designing, making and evaluating technological artefacts. In many cases, this is done by involving students in a series of small-scale projects that focus on the development of particular manual and intellectual skills in ways that are progressive and cumulative. Experience confirms that technological knowledge is different in a number of respects from scientific knowledge, including form and purpose, and science and technology teachers both need to understand the nature and significance of these differences.

In general, behaviourist theories of learning have been a much stronger influence on educational practice, including both teaching and assessment, in the United States than elsewhere.

In the mid-twentieth century, the ideas of Piaget, Ausubel and Gagné gained considerable prominence, although much more so among primary educators than their secondary counterparts. Unquestionably, however, current ideas about how children learn are dominated by so-called ‘constructivist’ perspectives (Tobin, 1993). While the essence of constructivism, that the mind actively constructs knowledge, is hardly new, the relevant literature now spans a number of disciplines, including epistemology, pedagogy and cognitive psychology, and it is so riven by controversy (see, for example, Matthews, 1998) that a case can be made for avoiding entirely the use of the term, although not, of course, the central notion that ‘making meaning’ is an active cognitive process. As with all good teaching, science and technology teachers need to provide students with time and experience to allow such a process to occur.

As with many academic debates, such controversy has little immediate impact on the day-to-day work of teachers, although there may be a significant influence in the longer term.

Nonetheless, it is now commonplace that knowledge cannot be ‘given’ or handed over and received in the same way as a parent might give a child a book, a toy or a tool. Knowledge acquisition and the development of understanding require active engagement on the part of the learner. The consequences of this view for teaching, however, are by no means as straightforward as is frequently supposed. It does not, for example, require the problematic idea that science education is about ‘making sense’ of the world rather than concerned with establishing a valid scientific understanding of natural phenomena. More than enough has now been written to expose the subtlety and complexity of scientific ideas and their frequent divorce from common-sense understanding and experience (e.g. Wolpert, 1992). Similarly, ‘constructivist’ ideas about learning do not lead in any logical way to a rejection of the world as an external reality nor do they always require a ‘progressive or child-centred pedagogy’.

Whatever learning theory is espoused, the central task of the teacher in promoting learning remains that of choosing and deploying the method(s) most likely to help students learn what the teacher wishes them to know, understand or be able to do. In other words, the relative merits of different teaching strategies are to be judged principally by reference to student learning, although other factors are likely to be involved, such as the facilities and level of resources required, and the implications for class management and assessment. In broad terms, students learn most effectively when they are set clear objectives, are actively involved in their own learning, appreciate the relevance of their studies and receive regular and constructive feedback about their progress.

Some scientific and technological skills can only be acquired by involving students in practical activities. Such activities require significant levels of resourcing, although much use can be made of local materials and locally manufactured apparatus.

While there is no simple strategy for promoting effective learning in school science and technology, the essential preconditions would seem to include teachers with a good grasp of the subject-matter to be taught and the ability to translate this subject-matter in pedagogical knowledge. Also important are (a) effective lesson planning that takes account of what students already know and can do and builds upon it, and (b) the deployment of teaching strategies consonant with the learning objectives.

Policy guidelines

Given the above, what guidelines might be offered as elements of a policy for teaching science or technology that is likely to be effective in promoting students’ knowledge and understanding? There is, of course, no simple or unequivocal answer to this question, if only because teachers need to adapt their approach to suit the circumstances in which they find themselves. It is, however, possible to identify elements of teachers’ competence and work that are strongly associated with gains in students’ knowledge and understanding. Policies should thus be directed towards promoting among science and technology teachers:

- *A thorough knowledge and understanding of the subject-matter and skills to be taught.*
- *The ability to transform the subject-matter and skills into pedagogical subject knowledge appropriate to the age, ability and aptitude of the students being taught.*

- *A knowledge of the ideas about natural phenomena that students bring to lessons and an ability to exploit these in ways that ensure progress in students' knowledge and understanding.*
- *An understanding of the ways in which technological knowledge is different in form and purpose from scientific knowledge.*
- *Effective lesson planning, incorporating clear intended learning outcomes and high expectations of students.*
- *The deployment of teaching methods, techniques and resources, including the skills of other staff, appropriate to the intended learning outcomes.*
- *The regular use of suitable high quality assessment instruments, including oral questioning, to monitor the effectiveness of teaching and to provide ongoing 'feedback' to students about their difficulties, progress and achievements.*
- *The skilful use of homework to support, reinforce and extend the work done in school.*
- *The ability to manage students in the classroom, workshop, laboratory or in the field, in ways that promote their interest in, and knowledge and understanding of, science and of its relationships with other subjects and its interaction with technology and society.*
- *Knowledge of the technologies familiar to students and an ability to exploit these to promote science and technology education.*
- *A commitment to ongoing professional development as a teacher.*

Doing practical work

It is widely assumed among teachers of science that 'hands-on' experience, not necessarily in a laboratory, is an essential component of science education, and many claims have been made for such work. Regrettably, however, there is little agreement among teachers about the purposes of the practical work in science, and there has been little systematic analysis of what realistically can be achieved. This is partly because practical work has been expected to effect such a broad range of different learning outcomes, including the cognitive, affective and manipulative, that the outcomes of individual practical exercises have rarely been defined in terms that can be measured. In addition, a deeply held commitment to 'hands-on', practical teaching has arguably made science teachers somewhat reluctant to consider other approaches to teaching science that may be more cost-effective in achieving at least some of the learning outcomes traditionally associated with, for example, laboratory work conducted by students. From the perspective of educational policy-makers, therefore, it is important to ask not only whether the goals of practical work are being achieved, but also whether at least some of them can be achieved more economically. It is also important to recognize the major differences that exist between some education systems in the practical teaching of science. In the developed world, practical work in a well-equipped laboratory is the norm. In some developing countries, neither students nor teachers have access to a laboratory, and the teachers themselves lack experience of planning and managing practical classes.

The goals of practical work in science typically include the following: (a) encouraging accurate observation and careful recording; (b) promoting simple scientific methods of thought; (c) developing manipulative and problem-solving skills; (d) demonstrating facts and principles; (e) helping students understand more theoretical aspects of science; (f) arousing and maintaining interest in science; and (g) developing competence at carrying out scientific investigations.

However, teachers and students often have significantly different views about the purposes of practical work and, within some education systems, there is a marked tendency for assessment procedures to determine the work that is done in the laboratory. One major consequence of the latter is that the learning outcomes and assessment criteria for laboratory activities come to coincide in ways that severely restrict the educational potential of practical science. In these circumstances, practical work is reduced to a set of routine exercises that may satisfy assessment criteria but have little else to commend them.

In a comprehensive review of the literature relating to practical work in school science, Hodson (1993) draws distinctions between 'learning science', 'learning about science' and 'doing science', and he points out that that it has often been assumed that these significantly different goals can be well served by the same kind of learning experience. In addition, he warns that because 'experimentation' is central to science, many commentators have failed to draw the crucial distinction between 'doing science' and 'teaching/learning science' and thus wrongly assumed that it should also be central to science education. He goes on to argue for a generous definition of practical work that does not always involve activities at the laboratory bench. He cites, as examples, interactive computer-based activities, work with case-study materials, interviewing, debating and role-playing, writing tasks of various kinds, making models, posters and scrapbooks, library-based research, taking photographs and making videos. Some of these elements of practical work may, of course, be carried out in places other than a school • e g. in museums and science centres, on field trips in a variety of rural, urban or industrial environments. It is important to note that there is evidence that practical activities as computer simulations and role-playing can lead to enhanced student motivation and learning.

The main educational questions raised by the extensive writing on the practical teaching of science are as follows:

1. What are the purposes of the practical teaching associated with the major elements of the science curriculum and how do these fit in with the broader aims of school science education? Practical activity is not self-justifying. It requires justification in terms of what it encourages students to learn, and to do that is educationally worth while.
2. To what extent is the practical teaching of science determined by assessment requirements and how far can this be justified in educational terms?
3. To what extent is each of the practical activities undertaken in schools necessary and commensurate with the wider objectives of the science curriculum?
4. Is the amount of practical work undertaken commensurate with what students are likely to learn from it?
5. How cost effective is practical work compared with other strategies such as computer simulations or thought experiments that are likely to lead to some of the same learning outcomes?

As noted above, there are severe problems in some education systems in providing the facilities and equipment necessary to support the practical teaching of science and technology. Such constraints, however, underscore the importance • common to all education systems • of examining carefully the purposes of such teaching and of deploying the resources that are available to optimum educational advantage. Even at upper secondary level, many of the learning outcomes of school science can be realized through work that does not require laboratories and/or by making greater use of locally produced, low-cost equipment. Teachers may need help to exploit the resources of the local environment, museums and, where available, ICT, including the internet and the world wide web. In addition, financial constraints also provide an opportunity to revisit the design and maintenance of laboratories and equipment to reduce costs to a small multiple of those costs associated with building conventional classrooms. For example, what facilities does a laboratory incorporate for storage and maintenance, and does it allow demonstration as well as work done by students working individually or in pairs? To what extent does school laboratory design inhibit or discourage a range of teaching strategies such as role-play or games?

A further option is the building of specialized, multi-purpose rooms that can serve as science or technology laboratories when required. In all cases, data are needed to establish how effectively laboratory environments are used for whole class teaching and whether there are high-cost items of equipment that are used very infrequently.

Since designing and making are at the heart of school technology courses, appropriate practical accommodation, along with equipment, tools and other resources are essential. The facilities available need to be adequate to support the demands of the school technology curriculum but, as with the practical teaching of science, it is essential to ensure that the activities undertaken by students can be justified in terms of what students learn and are able to do as a result of engaging in them. Also, as with practical science, much can be achieved with the aid of local resources available outside the school.

What is perhaps beyond dispute is that practical activity has a fundamental role to play in science and technology education. Difficulties of implementation, teaching or resourcing, and debate about the educational purposes and outcomes of such activity, should not be allowed to obscure this fact.

Policy guidelines

- *Any policy for practical activities in school science and technology must rest upon knowledge of the extent to which the goals set for such work are being, or are likely to be, achieved.*
- *Research needs to be undertaken to establish whether some of these goals can be achieved as effectively by other, less-expensive means.*
- *Where laboratories and other facilities exist to support the practical teaching of science and technology, data must be sought to indicate how effectively they are used.*
- *The design of school science laboratories needs to be reviewed in the light of the range of work that is done, or could be done, in them.*
- *Where laboratories and workshops are not available to teach science and technology, guidance must be offered to teachers on how to conduct practical work, e.g. in the classroom, in the local environment or in places such as museums and visitor centres.*

School science and technology and gender

There are many sources of potential or actual discrimination within societies, including gender, race, language and accent, tribe, region and nationality. Exclusive attention to gender in this concluding section is not to be taken as an indication that these other forms of discrimination are less important or powerful. Rather it reflect the fact that attention on a global scale to a range of issues associated with gender and science, technology and vocational education was one of the remarkable features of the second half of the twentieth century. Despite some progress in addressing gender inequity in these fields of education, many problems and issues remain. Moreover, as Koblitz (1996) has indicated, where the position of women in science and technology has changed, such change has been neither constant nor linear, with earlier gains often being reversed.

Any examination of the issues surrounding gender, science and technology education must be placed in the wider context of gender inequity within education systems as a whole. Globally, some 100 million children of school age never attend school and some 60 million of these are girls. Women account for almost two-thirds of the world's illiterate population, a statistic that reflects the fact that, in a number of countries, boys have preferential access to schooling. In some parts of the world, the percentage difference in the gross primary enrolment rate for boys and girls exceeds 20 per cent and a study undertaken by the International Association for Educational Achievement in the 1980s revealed that the percentage of students aged 17•19 years enrolled in secondary education varied among the countries studied from 1 to 80 per cent, a difference that may have narrowed little in the intervening years.

In 1967, the General Assembly of the United Nations adopted a Declaration on the Elimination of Discrimination Against Women, a measure that was strengthened in 1980 when the Assembly adopted the Convention on the Elimination of All Forms of Discrimination Against Women. Between 1975 (International Women's Year) and 1985, the United Nations adopted an action plan for the newly designated Decade for Women. Several world conferences on gender issues and development have been held and a number of statistical surveys, outlining trends across Member States, have been published (e.g. UNESCO, 1991). The education of women and girls was the theme of UNESCO's *World Education Report 1995* and special emphasis was laid on the gender dimensions of science in UNESCO's *World Science Report 1996.* In the Beijing Platform for Action adopted at the Fourth World Conference on Women, it was acknowledged that a renewed emphasis needed to be given to increasing the number of girls and women in science, technology and vocational education, and to improving their participation in technology for development in several fields, including food production, water supply and sanitation. A review of issues, policies and strategies was published by UNESCO in 2000 in a volume that also contains a number of regional and country-specific studies (Jenkins, 2000). Gender issues, not least in science and technology education, have also been a focus of attention for the Commonwealth Secretariat. *A Plan of Action on Gender and Development* was adopted in 1995 and this has since been updated to cover the period 2000 to 2005. The secretariat has also published advice to governments and other stakeholders on gender mainstreaming in education (Leo-Rhynie et al., 1999).

If progress is to be made towards gender equity in schooling, governments must make a political commitment to, and support for, gender equity in national plans and priorities. Education policy needs to articulate with national targets and goals, and resources need to be found to address, where they exist, serious inequalities in educational provision, e.g. in the laboratories and equipment available in boys' and girls' schools.

Clear policies on gender issues must be developed for schools and other institutions concerned with scientific and technological education. Consideration should be given to providing single-sex education in science and technology for at least part of compulsory schooling by, for example, teaching segregated classes within co-educational schools. Attention needs to be given to the interactions that take place within classrooms, laboratories and workshops by, for example, increasing the awareness of teachers of gender issues, adopting a variety of collaborative teaching styles and encouraging teachers to engage with research into their own practices. Every effort should be made to ensure that curriculum content, school textbooks and other curriculum materials are as free as possible from gender bias by, for example, showing women scientists and technologists at work, adopting non-sexist language, and addressing aspects of science and technology (including information and communication technologies) that girls may perceive as discouraging or remote from their interests. In addition, it is necessary to address those aspects of science and technology (including information technology) that are regarded by most girls as discouraging or remote from their interests by, for example, developing or adapting courses to accommodate issues that girls are likely to find relevant.

In many countries a variety of out-of-school strategies has been developed to increase the participation of girls in science and technology education. Examples include summer camps, 'road shows', science 'clinics', 'taster' courses, exploiting the potential of interactive science centres, visiting research laboratories, and making available simple equipment for use in primary schools and/or at home (Jenkins, 2000). Opportunities should be provided to develop girls' confidence in handling equipment and apparatus, including computers. These experiences are often part of wider programmes to popularize science and technology more generally (Ramanathan, 1999; Commonwealth Secretariat, 1997, 1998*a*, 1998*b*) and experience shows that if such programmes are to be effective in the longer term, 'follow-up' work within schools is required. Role models for girls are also important. Strategies include encouraging contact with successful women scientists and technologists, using radio, television or the print media (see, for example, Mschindi and Shankerdass,1998), involving parents, establishing links with female science or technology undergraduates, and adopting effective mentoring procedures.

In seeking a curriculum response to gender inequity in science and technology education, it is important to avoid oversimplified generalizations about the issues involved, or automatically extrapolating research findings and strategies from one education system to another. There are many different sciences • and many different technologies • and a valid explanation of, or a successful strategy for dealing with, gender issues in one culture may be quite inappropriate, or even counterproductive in another. There are dangers, too, in assuming that the gender issues surrounding science education are the same, or necessarily have the same origins, as those involved in technology education. Nonetheless, in all societies and cultures, boys and girls are reared differently according to their sex and there are different assumptions about the social roles that they are expected to fulfil as adults. Given this, it is hardly surprising that comparable gender differences are found in widely different social, political and economic contexts, though the form in which they are manifest is likely to be more specific.

Any action that might be taken to address gender inequity in school science and technology and, in particular, to increase the numbers of girls and women engaged in scientific, technological education and employment requires a careful diagnosis of the nature of the problem(s) to be addressed. Where, as in some countries, there are powerful social and cultural influences that are hostile to the scientific and technological education of girls, the impact of any changes in the school curriculum intended to promote such education will necessarily be modest. Equally, however, changes in a school curriculum can signal a government's intentions and commitment to school principals, teachers, students, parents and the wider community that the school is meant to serve.

In addition, caution is necessary in considering the transfer of tactics and strategies designed to promote gender equity from one educational system need to another. What is appropriate and effective in one context or country may be ineffective or even counter-productive elsewhere.

Nonetheless, there have been a number of initiatives that have met with some success in promoting the scientific and technological education of girls and in promoting great gender equity in scientific and technological education. In general, the message seems to be that addressing the problems of such inequity in school science and technology requires co-ordinated action on a number of different fronts. There are roles, for example, for government, for schools and those that work within them, for professional scientists and technologists, for education publishers, for higher education, for parents and for a variety of non-governmental organizations.

Policy guidelines

- *Governments must make a political commitment to, and support for, gender equity in national plans and priorities.*
- *Gender-sensitive strategies must be incorporated within all those fields of policy and action where government has responsibility and/or influence.*
- *Clear policies on gender issues must be developed for schools and other institutions concerned with scientific and technological education.*
- *Role models are important for students, and strategies need to be developed to promote them.*
- *Programmes of carefully structured and out-of school experiences, with appropriate school-based follow-up, should be developed to promote girls' interest in science and technology.*
- *Every effort should be made to ensure that curriculum content, school textbooks and other curriculum materials are as free as possible from gender and other forms of bias.*

The initial training of teachers

During the last two decades, the training and professional development of teachers of science and technology have become matters of concern in many countries, irrespective of whether the economies are high or low income. Not surprisingly, however, the difficulties of improving the quality of scientific and technological education are much more severe in low- or middle-income countries than in the industrialized nations. More is involved here than limited human, material or financial resources, political instability or an expanding population to be educated. There is the underlying problem, common to all countries, of understanding which factors are likely to be most significant in raising standards. Without such understanding, it is almost impossible for policy-makers to judge how best to deploy limited, and often severely limited, resources. There has thus been a worldwide interest in what is sometimes called 'school improvement', an interest that, of course, extends beyond the teaching of science and technology.

Despite some lack of universal agreement about what constitutes 'school improvement', it seems that large advantages accrue to those cultures which can generate 'strong systems' of education, compared with those societies that rely on the necessarily finite numbers of people with the personal characteristics to generate effective practice (Reynolds et al., 2000). Effective programmes of initial and teacher education are a major feature of such 'strong systems' and it is important that such programmes ensure that teachers have sufficient breadth in the subject(s) they are to teach to be both confident and effective.

A distinction is often drawn between concurrent and 'end-on' programmes of initial teacher education. Although there are many good concurrent programmes, the science and technology components of others are often less than adequate and those responsible for teaching them often need their own knowledge of, and expertise in, science and technology updating. 'End-on' courses are of shorter duration and often follow a more specialized degree level study of one or more of the sciences. As the demands upon science and technology teachers change, e.g. with the development of courses concerned with science, technology and society, the limitations of what can be achieved during these shorter courses become more evident.

During the last decade or so, traditional approaches to teacher training, traditionally 'top-down' and prescriptive, have been called into question, along with the notion that teacher trainers and administrators understand better the teaching process than those actually engaged in teaching in the schools. While, as Layton acknowledges (Layton, 1992, p. 14), 'it would be unwise to reject this tradition in its entirety', since both beginning and more experienced teachers can undoubtedly be helped by others to improve what they do in classrooms and laboratories, many education systems have given the schools themselves a greater role in both the initial and the in-service training of teachers, redistributing the financial resources accordingly. Ideally, such training makes particular use of schools that are judged to be successful, although this is not always possible, and there are likely to be particular problems with small and/or isolated schools. In addition, some of those who are good at teaching science or technology to school students may not be so successful at training teachers, many of whom are likely to be adults. If schools are to play a significant role in training teachers, then profound changes are needed in the ways in which schools have traditionally perceived their role. They will need to become skilled at developing the competence and confidence of the student teacher and ensure that he or she has a valued and recognized role to play in the school as a learning environment. Student teachers can become more confident and competent in a variety of ways, not all of which involve assuming full responsibility for the work of a class. Partnerships of various kinds are thus to be encouraged: partnerships between experienced and novice teachers, between schools themselves, and between schools, training colleges and other institutions of further and higher education. Private schools also have a role to play in teacher education, although the nature and extent of that role will vary from one education system to another.

Developing and maintaining such partnerships, however, requires time and demands adequate funding. Siting initial teacher education largely or entirely in the schools is more expensive than undertaking such work in specialized institutions. School 'mentors' need themselves to be trained and there can be difficulties in maintaining standards and assuring quality. These difficulties may become acute when there are high levels of staff turnover in the training schools. Specialized teacher training institutions also offer greater opportunities for students to learn from one another, to support each other in dealing with difficulties such as those arising from class management, and to access and use a much greater range of equipment and other resources than is likely to be available in any one school. Perhaps only two points can be made with confidence. First, whatever system of initial teacher education is in place, it must accommodate the diverse needs of students, allow for the fact that novice teachers develop into competent classroom practitioners at different rates and in different ways, and incorporate appropriate mechanisms to help such teachers develop their professional skill and expertise. Secondly, central to teacher education is work with students in classrooms and laboratories, referred to variously as 'teaching practice' or the 'practicum'. Different education systems have different ways of relating this work to other aspects of teacher education but recent research suggests that there are benefits in providing students with some practical experience of this kind before, rather than after, they embark on other aspects of their training.

Similarly, whatever the form and content of initial teacher training courses, they must all be concerned with the development of the science or technology teacher's personal pedagogical subject knowledge. The notion of pedagogical knowledge reflects the fact that much more is involved in teaching than a knowledge of subject-matter, essential though this is. It also requires knowledge of learners and of learning, of curriculum and context, and of aims and objectives (Grossman et al., 1989) because it is fundamentally concerned with the act of teaching. It is essentially 'knowledge in action', embraces much more than can be made explicit, and accommodates judgements that cannot be supported in abstract and general terms but only in the particularities of the situation in which a teacher is working with students, and then frequently only by an appeal to experience.

For those concerned with teacher education policy and, in particular, with improving teacher quality, the attractions of a well-defined technology of teaching are obvious and there have been a number of moves in this direction. Such a technology might depend upon the following three broad components:(a) pedagogical knowledge and understanding required by trainees to secure students' progress in science and technology; (b) effective teaching and assessment methods; and (c) trainees' knowledge and understanding of science and technology. Each of these three components can then be elaborated to provide detailed guidance for those involved in the preparation of teachers. Pedagogical knowledge and understanding, for example, might involve four elements, concerned respectively with teaching intending teachers why it is important for students to learn science or technology, the nature of progression in students' scientific and technological knowledge and understanding, the key aspects of science and technology underpinning such progression, and the importance of engaging students' interest in science and technology. Each of these four elements can then be further elaborated to specify what intending teachers must be taught, e.g. that students' own 'everyday' understanding of some scientific concepts will often differ from those they are required to learn, the possible origins of these 'misconceptions' and how they can be addressed.

A competence-led model of teacher education specified in these terms may claim a number of advantages. It sets targets for both teacher educators and those whom they prepare to enter the teaching profession. It allows teacher education to be inspected against a set of criteria so that any weaknesses can be addressed and improvements made. In addition, schools who receive newly qualified teachers will know what to expect from them, especially if the outcomes of the training course are specified in the form of a career entry profile. Such a profile has also constituted a basis upon which programmes of induction and further professional development can be constructed.

The advantages of a competence-led approach to teacher education should not, however, be overestimated. As noted above, teaching cannot be reduced simply to a set of competences, and standards of teaching and learning are unlikely to be raised by deploying a routine practice unless such standards are very narrowly defined. The extent to which a strong and uniform technology of agreed practice in teaching is adopted will depend in large measure on the assumptions made about the purposes of schooling within the wider society that the schools exist to serve. For example, are schools mainly about helping children to 'move at their own pace' or are they about ensuring that every student meets some specified standard of achievement? In education systems/countries such as Hong Kong, India and Taiwan, it is the latter view which prevails, but in others, including those who share what might be called the Anglo-Saxon tradition of schooling, it is widely accepted that children should be allowed to progress at their own pace.

A competence model of teaching also has implications for teacher professionalism. By opening teachers' work to careful specification and to detailed monitoring and accountability, it runs the risk of standardizing practice at the expense of innovation and creativity. In addition, as with any other occupation, teachers will direct their energies to those tasks for which they are to be held publicly accountable, to the detriment of other, perhaps more educationally worthwhile activities.

It is, of course, possible to argue that identifying and emphasizing the 'competences' involved in teaching complements and enhances the professional expertise of teachers. For some, this argument is valid only if it is combined with an understanding of teachers' work that acknowledges the wide diversity that stems from the context of individual teachers working in the particular circumstances of a school, classroom, laboratory or group of students. Others, however, assert that this diversity is largely an irrelevance and, to the extent that it is not, can be overcome by a suitably strong technology of practice. Both views are currently evident in the literature about school standards and they represent fundamental differences of view about how to raise teaching quality that reflect the wider social assumptions about schooling referred to above. The underlying issue, in terms of both standards and teacher professionalism, is the extent to which teachers, including teachers of science and technology, should be free to determine their own pedagogy.

Policy guidelines

- *Steps need to be taken to develop effective partnerships between schools and training institutions. The nature of these partnerships needs to be carefully defined with well-defined roles allocated to those involved. Financial and other resources must be deployed in ways that reflect these roles.*
- *Policies for teacher training must give a key role to experienced teachers in training students and provide the necessary assistance, e.g. mentoring programmes, to enable them to fulfil that role.*
- *There is evidence to suggest that there are benefits in allowing student teachers to spend time working in schools before, rather than after, they embark upon other aspects of their training.*
- *Those involved in science and technology teacher education must be associated with the reform of school science and technology curricula so that teacher education programmes do not become out of touch with the work of the schools.*
- *A teacher training policy must specify the skills and knowledge required of newly qualified teachers in the light of the work they will do in the schools in which they will teach.*
- *Teacher training policies need to recognize that intending teachers need more than subject knowledge. Teacher training programmes must therefore help student teachers to transform this into a form of knowledge (pedagogical subject knowledge) that is appropriate for the task of teaching.*
- *Courses of initial teacher training need to form part of a coherent programme of professional training, induction and development.*

Recruiting and retaining teachers

It is widely assumed that in many countries people with scientific or technological qualifications are in short supply. While this is indeed the case, there is evidence to suggest that a few countries may have begun to produce more science graduates, especially pure science graduates, than can be employed in jobs that make use of their specialized scientific skills. In contrast, in these same countries, the shortage of personnel with qualifications in applied science, engineering and technology often remains endemic. School science teaching is a major sector of employment for pure science graduates but the supply depends on a variety of factors over which the schools themselves have little or no control. In many countries, a detailed analysis of the supply and demand for science-qualified school-leavers and graduates is hindered by a lack of up-to-date and reliable data. In these circumstances, employment and career opportunities are likely to be made on the basis of such factors as personal preferences, hearsay and perceived occupational stereotypes rather than a realistic and informed appraisal of the possibilities.

In many countries, especially those in Africa, the proportion of students enrolled in science and engineering courses in higher education is low. Given the costs of equipping and teaching these courses, the unit cost is very high. In addition, this educational investment often produces disappointing economic returns. There are several reasons for this. Those with scientific or technological qualifications may secure employment in other countries. Salaries, too, are important. In most countries, government is the largest employer of those with scientific qualifications and the salaries of teachers, as public servants, are often significantly lower than can be commanded in other sectors of the economy.

When the difficulties of recruiting and/or retaining adequate numbers of science and technology teachers are severe and enduring, both short- and long-term strategies are likely to be needed to overcome or reduce them. The former include special bursaries, fee concessions for higher education or teacher training or other financial inducements to attract potential science teachers; providing for adequate salary progression and career development for those in post, and recognizing and rewarding successful teachers in a variety of ways, e.g. by bonus payments for longer service. The funding of institutions of higher education might also be done selectively in ways that encourage the recruitment of students in the scientific and technological disciplines.

In the longer term, steps can be taken to improve the participation rate in science and technology education, particularly at the lower and upper secondary level. This may involve compulsory programmes of science and technology education to help establish science and technology as integral and essential elements of general education. Legislation can prevent those who might opt out of science or technology education, notably girls, from doing so, with a consequent narrowing of career opportunities and a loss of national scientific and technological talent.

In some countries, the pool of potential entrants to the teaching profession can also sometimes be enlarged by drawing upon those who, although suitably qualified, are not currently employed. This is likely to involve not only suitable recruitment campaigns, using print and broadcast media and recruiting agencies, but also the provision of suitable 'refresher' or updating courses. Schools may also need to be more flexible in the ways in which they make use of the science teaching expertise at their disposal. Industry and higher education can be encouraged to second staff to work in schools.

The print and broadcast media and other organizations also have a role to play in persuading students and their parents of the merits of science and technology teaching as a profession. This may involve successful science and technology teachers serving as role models, stressing the importance of human resource development to national economic prosperity, organizing promotional events such as 'science fairs', encouraging science and technology undergraduates to visit/work on a short-term basis in schools, and helping parents and others understand more about the nature of the work undertaken by school science and technology teachers.

Much can sometimes be gained by reviewing the way in which science and technology teachers are used in school. Science and technology teacher deployment is often less efficient than it might be, even in middle- and high-income economies where shortages in some schools can coexist with surpluses in others. In addition, science teachers sometimes teach subjects for which they have no training, and science itself is sometimes taught by teachers without any scientific qualifications. Given that science teachers' salaries are the largest recurrent cost in teaching science, more attention needs to be given to the effective deployment of this resource than is usually the case. Ideally, the staffing of school science and technology needs to be related by formula to the numbers of students studying the different scientific subjects at various levels. A further issue in many education systems is the match between the staff needed to teach integrated science courses and the graduate output from higher education where specialization in one or two science subjects is the usual pattern of undergraduate study.

Finally, much work needs to be done to establish the contribution that information and communication technologies can make to optimizing the use of science and technology teaching expertise.

Policy guidelines

There is no simple or universal solution to securing an adequate supply of those with scientific or technological qualifications to work in the schools. The following need to be considered in the light of the circumstances prevailing in individual education systems, including the financial and other resources needed to sustain the various policy initiatives:

- *Where there are recruitment difficulties, both short- and long-term financial and other strategies must be developed to recruit, retain and motivate science and technology teachers for the schools.*
- *The print and broadcast media and other organizations should be used to promote science and technology teaching as a career.*
- *Where appropriate, policies should be introduced to attract into school science or technology teaching those who, although suitably qualified, are not currently working.*
- *Attention must be given to the ways in which science and technology teachers are deployed in schools.*
- *Research should be undertaken to establish the ways in which information and communication technologies and distance learning can maximize the use of existing science and technology teaching expertise, including expertise from other education systems.*

Induction and professional development of teachers

Programmes to induct newly qualified teachers into the profession are an integral part of teacher education and of teachers' professional development. It is to be regretted, therefore, that in many education systems, such programmes are ill-thought out, under-funded or even non-existent. In addition, there is sometimes uncertainty about where the responsibility for organizing and funding induction programmes lies. Is it the responsibility of the subject department, of the school and its head teachers and managers/governors, or of local, regional or national government? In most education systems, the responsibility will be divided and, where this is the case, the nature of the divisions must be clear to all concerned. Whatever the division of responsibility, several general points can be made:

1. Just as a competence model of teaching can be used to structure initial teacher education, a similar approach can be used to develop induction programmes for those who are newly qualified. Where career entry profiles are available, these can be invaluable as an indication of training needs and as a recording device. Such a profile should indicate the newly qualified teacher's experience and strengths, together with possible weaknesses where help may be needed. In many cases, however, it will be for a school to re-assess the induction needs of a newly qualified teacher and to set and monitor targets appropriately. Individual professional development needs must be distinguished form other needs that are essentially school, local, regional or national, so that the appropriate authorities can develop policies to support them and allocate resources accordingly. The professional needs of teachers should be kept under annual review and form part of a system of school-based appraisal that commands widespread confidence.
2. Induction programmes inevitably cost money, although some of the costs are likely to stem from reducing the contact time of newly qualified teachers with students and/or from releasing experienced teachers to act as mentors. While the expenditure can properly be regarded as an investment in linking initial teacher education with professional practice, policy-makers will wish to know the extent to which induction programmes improve the quality of teaching and learning. The data that are available suggest that well-conceived programmes of induction can help newly qualified teachers to stay in the profession, enhance their sense of professionalism and reduce the difficulties they encounter in managing classes of students.
3. The needs of newly qualified teachers are by no means always subject specific. Induction programmes thus need to take account of wider departmental or whole school matters as well as such issues as classroom and laboratory management.
4. Feedback on lessons that have been observed by experienced teachers is valued highly by newly qualified teachers, providing such feedback is seen as a contribution to better practice and not merely as a criticism.

5. The induction requirements for newly qualified teachers need to be located in a wider national or regional framework so that schools and teachers are working towards broadly common standards of professional competence.

All professional development involves learning. The consequence is that the longer-term, ongoing/in-service education of teachers is a *sine qua non* of educational change. Such change, however, is complex and involves much more than the introduction to new ideas or practices with which much professional development has traditionally been concerned. In particular, attention needs to be given to how such new ideas or practices can be implemented to become integral to teachers' work. Resources for ongoing help and support for teachers are crucial to the success of any attempt at changing teachers' work. Thus, while short in-service courses for teachers have value, their contribution to improving schooling is necessarily limited, the more so when they do not form part of a coherent programme of professional development.

Central to any programme of this kind is a model of what is entailed in such development. Teachers will differ in their professional needs and aspirations, and the demands made of them by, for example, central government, will change over time. It is necessary, therefore, to develop a model of teacher professional development that accommodates both of these dimensions and to support it in appropriate ways. These include not only providing the financial and other resources needed to support development programmes but also reflecting enhanced professional competence by, for example, schemes of performance-related pay.

Much professional development of science and technology teachers can be based in a school or a group of schools, with attention being given to issues of common professional concern. However, science and technology teachers also need opportunities to learn about advances in scientific and technological knowledge and techniques and to relate these to their own teaching. Contact with institutions of higher education, with business and with manufacturing and other industries is therefore also important. They also need time to transform newly acquired knowledge, ideas and techniques into their personal pedagogical subject knowledge. Discussion with other teachers within a school or a subject teaching association is likely to be helpful in this regard. Time for such discussions should form part of the professional time available to science and technology teachers.

Policy guidelines

There are no universal strategies for teacher induction and for promoting the professional development of teachers but research suggests that the following are important:

- *Induction programmes for newly qualified teachers should be based on a career entry profile prepared by the teacher in conjunction with the institution at which he or she was trained.*
- *Programmes of teacher induction and in-service training need to be part of a coherent, school-based programme of staff development that may, in turn, form part of a regional or national framework.*
- *Individual professional development needs must be distinguished from other needs that are essentially school, regional or national, so that the appropriate authorities can develop policies to support them and allocate resources accordingly. The professional development needs of individual teachers should be determined by a system of school-based, annual appraisal that commands widespread confidence.*
- *The professional development needs of teachers of science and technology include updating their scientific/technological knowledge and skill. This is likely to involve collaboration with universities or other institutions of higher education and with*

industry. Such collaboration should be actively encouraged and supported by appropriate funding mechanisms.

- *As much attention needs to be given to the processes involved in changing what teachers do as to the innovation itself.*
- *If professional development is to become an established feature of teaching as a career, it needs to be reflected in the reward structure of the profession by, for example, incorporating a performance-related pay threshold, and rewarding those teachers who are specially trained and highly competent. Such teachers have an obvious and important role to play in developing the competence of their less experienced and/or skilled colleagues.*
- *The ongoing development of science and technology teacher competence will require partnerships of different kinds, involving, for example, government, institutions of higher education, universities, industry, school teacher training colleges, professional and subject teaching associations, and NGOs. Steps therefore need to be taken to promote such development. The contributions that each of the partners may make to teacher development will be enhanced if their individual roles are clearly defined in ways that allow them to make effective contributions to be made to a coherent programme.*

Time must be allowed for teachers to transform newly acquired scientific knowledge into their personal pedagogical subject knowledge and to assimilate and make use of newly acquired knowledge and skills.

Language as a key factor

The language in which science or technology is taught in a school that serves a multi-lingual community is usually determined by reference to wider political considerations rather than to narrower educational concerns that might relate, for example, to the notion of 'best practice'. In addition, decisions about the language to be used in such schools often have implications well beyond the school system itself. As a result, almost any decision about the language of instruction to be used within such a school system is likely to be controversial.

In the case of science itself, English is arguably the lingua franca of international communication, and it is important to recognize that the development of a scientific language was integral to the development of science itself. It is thus hardly surprising that some languages do not possess the vocabulary needed to express scientific concepts and that inappropriate and unhelpful associations can be generated when words are simply translated to overcome this difficulty, as when concepts in physics that are distinct, such as force, power, energy and work, are translated into a single term in the South African languages of Sotho and Zulu. However, coining appropriate new words allows the meanings of those words to be conveyed in a cultural context. This is the strategy followed in, for example, New Zealand which has developed a curriculum employing the medium of Maori languages that takes account of Maori culture. In India, a glossary of scientific and technological terms has been developed in Hindi. It needs to be recognized, however, that the difficulty extends beyond that of a specialized vocabulary, since the structure of the two languages is also involved.

As far as instruction is concerned, it is commonly accepted that expecting students to learn science through the medium of a second or even a third language presents them with the complex task of meeting the demands presented by both the subject and the language. Bilingualism can, of course, confer some advantages, not least the ability to understand how the same idea is expressed and understood in two different languages. Little seems to be known, however, about how bilingualism might be exploited to promote students' learning. In addition, so-called 'code switching' between two languages in which a speaker has some measure of confidence is found at all levels of education, from early primary school to the teacher training level. Teachers can, of course, exploit this code switching, subject always to the limitations of initiation into the social practice of science referred to above.

Instruction for a substantial part of schooling should be in the home language or in two languages with strong home language support (Rollnick, 2000), although, as noted above, the challenge of learning science is far greater than learning the meanings and use of words. When it is decided at what level a different, international, language is to be used to teach science, adequate transitional arrangements need to be made. In some education systems, the local language is used to teach science but students are also taught English to help them to learn from the Internet and other sources.

It would be a mistake to assume that language difficulties are confined to students, since teachers who teach in their second language are also likely to encounter problems. Where teachers are poorly qualified in science or technology and have a poor command of a language, they are unlikely to be able to make effective use of science or technology texts in that language and that are often the only resource available to them. Language problems, however, are not confined to second language speakers, since the teaching and learning of science can present difficulties even for first language speakers. This is partly because of the differences between everyday language and scientific language and partly because the learning of this scientific language involves initiation into another social practice. Learning science in a second language thus involves initiation into two social practices, a burden that has led some commentators to argue for the use of the home language to facilitate 'border crossing' between the learner's own culture and that of science (Aikenhead and Jegede, 1999).

If second language instruction in science or technology is to succeed, several conditions must prevail. Teachers must be proficient in the second language, must understand the problems students face in learning science in that second language, and be able to help them overcome them. Graded language textbooks are needed, especially in the early phases of learning. Beyond the school, there must political support for the language strategy, manifest in terms of official commitment and resources.

Finally it should be noted that language policy must acknowledge that so-called 'best practice' in teaching science or technology cannot be readily transferred from one education system or culture to another. While there is evidence that second language students learning science in a second language can be taught to pose questions, construct hypotheses and undertake scientific investigations, learners within authoritarian cultures may benefit from a more didactic and explicit approach which others from a different culture might judge too 'teacher-centred'.

Policy guidelines

Despite the complexity of the issues surrounding language and instruction, a number of broad conclusions can be drawn:

- *Instruction for a substantial part of schooling should be in the home language or in two languages with strong home language support. When it is decided at what level a different, international language is to be used to teach science or technology, adequate transitional arrangements need to be made.*
- *If second language instruction in science or technology is to succeed, teachers must be proficient in the second language, must understand the problems students face in learning that second language and be able to help them overcome them.*
- *In translating scientific and technological terms and concepts from one language into another, consideration needs to be given to the case for coining new words.*
- *Language policy for teaching science or technology cannot be readily transferred from one education system or culture to another.*
- *All teaching materials should be designed with language issues in mind.*

Using information and communication technologies (ICT)

There seems little reason to doubt that contemporary information and communication technologies (ICT) can make significant differences to the quality of both teaching and learning. However, the nature of the differences is incompletely understood, not least because teachers and students are still finding new ways of working with ICT and the technologies are themselves undergoing development. In addition, any learning benefits associated with the use of ICT depend upon how these technologies are used since, as a resource for teachers and students, they can be used well or badly. Making effective use of ICT in teaching science or technology thus requires teachers to marry the potential for learning that the technologies offer with skill in deploying them to achieve clear learning outcomes. It is not sufficient for teachers simply to acquire 'computer skills', e.g. becoming competent at word processing or at working with data bases or spreadsheets. These skills need to be turned to educational advantage, i.e. to promote learning. Even in economically prosperous societies, within which access to a computer is largely taken for granted, there is much still to be learnt about how best to use ICT in this way.

The effective use of ICT also requires a clear policy framework at a number of different levels, from the school to local, regional and national government. Providing, maintaining and replacing the necessary hardware (e.g. desktop, pocket-book or palm-top computers) and software require resources that can usually be secured only at the expense of other commitments. In addition, in a field within which technological change is particularly rapid, almost all education systems face difficulty in keeping abreast of developments and innovation. The deployment of those resources also raises a number of policy questions, especially when they are severely limited. Many teachers would like to have ICT facilities based in their classrooms or laboratories so that they can use them whenever they wish to do so. Such a strategy, however, is very expensive and difficult to justify on educational grounds since ICT is not a resource to be deployed in every lesson. There is, therefore, a case for locating at least some ICT resources (e.g. desktop computers) centrally within a school and developing a school policy for their use, access, maintenance and security. In some education systems, such a central facility is likely to be beyond the resources available. In such cases, schools may be able to use a number of relatively low-cost palm-top computers or share ICT facilities provided by dedicated ICT centres, although the latter arrangement is feasible only in urban areas where schools are not too far away from each other. As a locus of scarce resources of material and expertise, ICT centres have much to commend them, not least in providing in-service courses for teachers. However, experience suggests that however well teachers are trained in ICT, they will not use such technologies in their teaching unless the necessary resources are readily available and they receive support at the school level. There is a role here for advisory teachers who have been trained in the use of ICT as a teaching resource. Such teachers spend time with teachers in their own schools helping them to develop their expertise in the context within which they normally work and with the resources normally available to them.

Schools also need to develop an ICT policy that optimizes the benefits likely to be obtained from using the various technologies. Those benefits, reflecting the notion of ICT as a set of tools, are of different kinds but they fall broadly into the following four categories: (a) communicating ideas and information; (b) handling information; (c) modelling; and (d) measurement and control. Science and technology teachers and their students have exploited all of these uses and the literature is replete with examples of how data logging, graphing, computer simulation and spreadsheets have been used in school science and technology teaching.

Much has been made of the World Wide Web as a learning device, and there is no doubt that it is very rich curriculum resource, giving access to massive resources of information, ideas, people and experience. It is also perhaps the learner-driven medium *par excellence*, responsive to the interests and priorities of any individual or community of learners. However, while electronic access to the largest and continuously updated library of information and ideas allied with the possibility of instant global communication opens up exciting opportunities for education, the evidence is that if students at school are to make optimum use of what the World Wide Web has to offer, they will need guidance and advice from a skilled and knowledgeable teacher. Ensuring that such teachers are available is thus an essential component of any ICT policy.

Much has also been made of integrated learning systems (ILS) and tutorial-based technologies. Once again, however, the role of a teacher or adviser seems to be more important than some enthusiasts for such systems are ready to admit. Much more needs to be known about how individuals interact with computers and a clear distinction drawn between improved levels of computer performance and a genuine understanding of the underlying scientific concepts.

Despite the notes of caution expressed above, no education system can now fail to invest in ICT, which arguably has particular advantages for schools in countries with low-income economies. It is no less essential to plan and budget for the maintenance and renewal of ICT systems. Much science can be taught and learnt 'online'. Once a school has ICT that provides access to the World Wide Web, teachers can use the technology to: (a) have global access to scientific information, data bases, teaching materials and resources, including those provided by museums and science centres; (b) communicate rapidly with teachers in other parts of the world and engage in 'electronic conversation' about topics of particular interest, concern or difficulty in teaching science; (c) access the catalogues of major libraries in different countries; (d) undertake professional development leading towards initial or higher qualifications by following and completing 'distance learning' courses; (e) publish their own work or that of their students; and (f) access journals, virtual museums, etc., relevant to their work.

Students, of course, can use the World Wide Web in similar ways. Where resources permit, it is now common for students to seek information from a variety of sources on the World Wide Web to undertake a task set by their teacher. For example, students might be required to access and exploit a variety of astronomical sites, downloading data and photographs, to complete a project on a topic about the solar system or an individual planet. Such work can often be undertaken in small groups and does not require more than a single ICT facility, located in a school library or other centralized resource. In some countries, schools are involved in one or more science projects which exploit the capacity of the World Wide Web to put schools in different countries in electronic touch with each other. The GLOBE project, for example, concerned with research into the environment, involves schools in data collection on a worldwide basis. Other initiatives include providing e-mail access to leading scientists and technologists, publishing the results of students' experiments online, engaging in virtual field trips, and the services of a 'Science Café'. The use made of ICT in teaching science and technology differs markedly from one country to another but, even in the most advanced countries, teachers and their students are still learning about what is possible. For a useful introduction to a rapidly changing field, see Scanlon (1997).

It should be noted that there is evidence that boys are more likely than girls to: (a) be interested in, and motivated towards, the use of computers; (b) have networks of friends interested in computers; (c) secure more of the teacher's attention when using computers; and (d) have access to the computing resources available. It needs to be stressed that these conclusions are based principally on research findings that relate to economically prosperous countries.

It is also important to recognize that the concerns about gender or other forms of inequity in curriculum materials may also apply to electronic sources of information and ideas. The data and imagery available from the World Wide Web reflect the interests and priorities of those who made the information available. These interests and priorities do not always entirely coincide with those of individual teachers, schools, communities or cultures, and there may sometimes be a direct clash. Students thus need to be taught to find information from a variety of sources, to select and collate such information to meet their needs and to question its accuracy, bias and plausibility.

Finally, attention is drawn to the potential of ICT to increase the disparities between the rich and the developing countries. The gap between the so-called 'info-rich' and 'info-poor' countries is widening and it threatens to relegate as much as 80 per cent of the world's population to a 'cyber-ghetto'. As the Director-General of UNESCO has recognized, it is necessary to facilitate the establishment of a universally acceptable 'public domain' of information to meet the educational and cultural needs of individuals and societies' (Matsuura, 2000).

Policy guidelines

- *The effective use of ICT to promote learning requires a clear policy framework at all levels of an education system, from government to individual schools and departments. Key elements of that policy will relate to such matters as the purchase of hardware and compatible software, the provision, location, maintenance and renewal of equipment, the staffing and training of technical support, the initial and in-service training of teachers, and the deployment and security of ICT resources within and between schools.*
- *That policy must budget and plan for the maintenance and renewal of ICT systems.*
- *Teachers must be trained to use ICT in teaching science or technology in ways that marry the potential for learning that the technologies offer with skill in deploying them to achieve clear learning outcomes.*
- *Resources must be provided at school level so that teachers can use ICT in their teaching of science and technology. Without adequate resources at school level any initial or in-service training of teachers in the use of ICT will be ineffective.*
- *While the setting up of centralized ICT facilities in a specialized institution, or within a school or groups of schools, has advantages, this necessarily limits the use that science and technology teachers can make of such facilities in their daily work.*
- *Pilot studies should be conducted of the ways in which the use of ICT can transform the way schools are organized and teaching conducted, e.g. by allowing more flexible use of time, more individualized and small group work, establishing electronic links with other schools, institutions, organizations, communities and countries, facilitating communication with government and with parents, allowing homework to be set, done and marked online.*
- *Policies should ensure that all those involved in the management and administration of an education service are aware of the potential of ICT and be trained to exploit it.*

Assessing and monitoring students' progress

The assessment of students' knowledge and understanding has always been a powerful influence on how and what teachers teach, although attitudes towards assessment are often ambiguous. For some, assessment is an effective means of bringing about change. If the examinations or tests change then, it is argued, so will the curriculum and/or the ways in which it is taught. For others, assessment is a straitjacket, preventing rather than encouraging change and, ultimately, inimical to education itself. Such attitudes are, of course, extreme and do scant justice to the role of assessment as an integral component of the teaching and learning process.

Fulfilling that role, however, requires different kinds of assessment instruments and strategies designed to serve specific purposes. These purposes typically include: (a) providing teachers with information about students' knowledge, understanding and skills to enable teachers and students to monitor teaching and learning; (b) using test results to allow progression through a school system or selection within it; (c) providing employers with confidence in, and details of, the outcomes of schooling; and (d) allowing governments or other agencies to monitor and compare the performance of schools and education systems. In broad terms, therefore, assessment is usually concerned with diagnosis, certification or accountability.

Diagnostic or formative assessment

Diagnostic or formative assessment is an integral part of teaching since it is concerned with establishing what students have learned and become able to do as a result of being taught and, if appropriate, changing the procedures in place to promote teaching and learning. It is thus a form of evaluation that needs to be undertaken on a regular and frequent basis and there is no doubt that it is of central importance to effective teaching. Garnett and Tobin (1989), for example, have concluded that 'the key' to the success of two different but exemplary teachers of chemistry was related to 'the way they were able to monitor for understanding'.

Such monitoring, however, must reflect what is known about how children learn, and be criterion-referenced rather than normative in its approach, although the difficulties in specifying assessment criteria in these terms should not be underestimated. If the criteria are broad and vague, they are of little diagnostic use. If, on the other hand, they are very specific, there will be many of them, making the assessment tedious to operate and encouraging an 'atomized' approach to learning (Black, 1993). Teachers may also find difficulty in operating with criterion-referenced rather than the normative assessments with which they are usually much more familiar. In addition, both teachers and students need to understand the function of formative assessment and to distinguish this from the role of so-called summative assessment. The latter offers a profile or summation of student achievement, often in the form of the results of an external examination, whereas the former is essentially concerned with advice, support and guidance and is directed towards improved learning. Formative and summative assessments thus do not always sit comfortably together. Surmounting these and other difficulties requires teachers and schools to establish how they can best generate the information they need in order to monitor and improve students' learning.

Much remains to be done to establish formative assessment as an integral part of the teaching and learning process. The essential first step is to persuade teachers and policy-makers of the importance of formative assessment and to devote as much time and resources to its development as have been invested in the more familiar strategies for summative assessment, commonly associated with accreditation and certification. To take advantage of such development, however, it will be necessary to invest heavily in the training/retraining of teachers and to ensure that teachers, students, policy-makers, parents and others involved in education understand and support the implications of formative assessment for raising the standards of work in the schools.

The strategies available to help teachers monitor students' progress include: (a) activities such as reading, viewing video or other material, conducting simple experiments, classroom debates, explaining or making class presentations about natural phenomena and 'pre-tests', to establish what students already know; and (b) familiar classroom or laboratory activities, such as oral questioning and writing assignments, to provide 'feedback' to both students and teachers that the latter can use to improve the effectiveness of further instruction.

It is worth emphasizing that any teaching programme rests upon assumptions about progression in students' learning. In some cases, such assumptions find expression in national curricula in the form of specified learning outcomes that can be broadly related to chronological age. In education systems with a national curriculum this is typically done by specifying 'attainment targets' and 'key stages', or 'strands' and 'achievement objectives' (see, for example, Bell, Jones and Carr, 1995). These set out the knowledge, skills and understanding that students of different abilities and maturities can be expected to have at various points in their schooling. In the United States, a country in which education is the responsibility of individual states rather than the federal government, 'national standards' have been developed, although these are very wide-ranging and include standards for science teaching, for science teachers' professional development, for science content and for science education programmes as well as for assessment in science education (National Research Council, 1996).

Underpinning these and similar initiatives to reform school science and technology education are assumptions about progression in students' learning. The initiatives also reflect a commitment to specifying and raising standards of attainment in ways that can be measured and reported to students, teachers, parents, school governors and managers, as well as the wider community. More particularly, as far as policy-makers are concerned, the specification and measurement of standards of student attainment permit some relationships to be established between educational input and output and, where appropriate, to direct or redirect scarce resources.

Policy guidelines

- *Teachers should be trained to understand that formative assessment is an integral part of successful teaching and to use a range of strategies to enable them to monitor students' progress.*
- *They should also be trained to understand that monitoring students' progress in understanding and skill requires: (a) a clear statement of what students are required*

to learn and to be able to do at various stages of their schooling; and (b) effective strategies for diagnosing and recording progress in ways that can be shared with students.

- *A policy for formative assessment requires a clear description of what constitutes 'progress' in science and technology education.*
- *Students should be encouraged to monitor their own progress and be taught the skills needed to enable them to do so.*
- *Policy-makers, parents and others involved in education need to understand and support the implications of formative assessment for raising the standards of work in school science and technology.*

Certification and accreditation

Most forms of certification and accreditation have traditionally relied upon norm-, rather than criterion-referenced, summative assessment. The distinction between norm- and criterion-referenced testing can, of course, be overdrawn since, in establishing criteria against which students' performance is to be measured, it is necessary to make some normative judgements about what it is reasonable to expect students to be able to achieve. Nonetheless, a criterion-referenced approach to assessment has a number of advantages. It identifies for students and their teachers the competences or skills upon which the assessment will be based. It also facilitates the construction of assessment instruments and makes it much easier to ensure a coherent relationship between assessment and the curriculum. However, judgements are still necessary about whether or not a criterion has been met, and by no means all the outcomes of science education can be reduced to operational statements of competence. There have been several responses to these difficulties, including the specification of bands of achievement that encompass the likely differences in the levels of performance of students of a particular age.

In many education systems, forms of summative assessment such as school-leaving examinations are used to select students for more advanced study, e.g. in secondary school or university. The reliability of such assessments as selection instruments is, at best, likely to be modest and much lower than specially constructed aptitude tests or entrance examinations. The latter are also likely to have a much-reduced 'backwash' effect on the work of the schools. However, the separation of certification from aptitude tests or entrance examinations is expensive and, for many education systems, not an affordable policy option.

In recent years, it has become clear that there is much to be gained by making greater use of competency based/criterion-referenced tests conducted by the teachers themselves. Such a strategy has the particular advantage that it allows a wider range of learning outcomes to be assessed than is otherwise possible. In most cases, however, it is appropriate to couple so-called internal/school-based assessments of students' performance with periodic standardized assessments conducted on a local, regional or national basis. These standardized tests can be used both to moderate teachers' individual assessments and to monitor the overall level of performance of the education system. Internal/school-based assessments have obvious advantages in the case of practical work in science and technology but if such an approach is to be successful, the following conditions must be met: (a) science and technology teachers must be thoroughly trained in assessment techniques; (b) an adequate educational infrastructure must be in place; and (c) students, their parents and the wider public must have confidence in the reliability and validity of the assessments made. This is likely to be particularly difficult when internal assessments contribute to the results of a selection process.

Where these conditions do not prevail, e.g. because large numbers of teachers are untrained and/or lack subject knowledge, the wiser short-term policy option is likely to be to concentrate on improving the sophistication, reliability and validity of externally set and marked examinations.

Policy guidelines

- *Teachers should be given responsibility for the summative assessment of their own students' work, provided that they are thoroughly trained in assessment techniques and supported by an adequate educational infrastructure.*
- *Where such conditions cannot prevail, attention should be focused on improving the sophistication, reliability and validity of externally set and marked examinations.*
- *Steps should be taken to ensure that the assessment process is transparent and widely understood so that students, their parents and the wider public can have confidence in the reliability and validity of the assessments made.*

The assessment of practical competence

It was noted earlier that the teaching of practical science is characterized by multiple and sometimes conflicting aims. Hodson (1993) has placed these aims in the following five broad categories: (a) to motivate students, by stimulating interest and enjoyment; (b) to teach laboratory skills; (c) to enhance the learning of scientific knowledge; (d) to give insight into scientific method and to develop expertise in using it; and (e) to develop certain 'scientific attitudes' • such as open-mindedness, objectivity and willingness to suspend judgement.

If assessment is to serve rather than dictate the curriculum it is thus essential to be clear about the learning outcomes of teaching practical science so that appropriate assessment strategies and instruments can be devised. Hodson's distinction between the curriculum goals of 'learning science', 'learning about science' and 'doing science', referred to above, is a helpful starting-point. The first of these three goals can be met in a variety of ways none of which involves practical assessment. The same can be said of the second goal. Only 'doing science' requires practical skills, but it is precisely this aspect of practical teaching that has traditionally been neglected both in the curriculum and in assessment procedures. There seems no reason in principle why students' competence at 'doing science' cannot be assessed, although attempts to do so, on either an atomistic ('skills') or a holistic basis both present difficulties.

Practical competence lies at the heart of technological capability and, as noted earlier, much effort is being put into developing ways of helping students develop this capability. No less effort has gone into developing appropriate assessment strategies. As with school science, so-called 'atomistic' approaches have been developed that assess students' competence on a series of 'discrete' skills. In each case, the weaknesses of such an approach are the same. Other strategies are more holistic and seek to assess students' technological competence in a more rounded way by means of small-scale projects or tasks. These projects and tasks are usually chosen so that, collectively, they represent a sequence of designing and making tasks that use a range of different materials and provide for progression of various kinds, e.g. in terms of the level of practical skill required or the associated scientific or other concepts. Despite some important curriculum initiatives, however, much remains to be learnt about how best to assess students' technological capability. What does seem clear is that, as with school science, teachers themselves have a key role to play. They therefore need to be trained accordingly.

Policy guidelines

- *School based/internal assessment of students' practical competence in science and technology should be preferred to external practical examinations, provided teachers are properly trained to undertake the assessment and confidence can be generated in the outcomes.*
- *Consideration should be given to the role of computer simulation in testing some of the outcomes that have traditionally been the focus of practical assessment (e.g. observation, data collection, presentation and analysis).*
- *Assessment policy must recognize that the resources available to support the practical teaching of science and technology are likely to vary from school to school so that the students involved in a practical assessment are unlikely to have a reasonably common experience of laboratory work. These differences are likely to affect their confidence and levels of performance on practical tests to a much greater degree than on written examinations.*

Assessment, gender and culture

When the first international comparison of students' achievement in science was undertaken in 1970-71, the results suggested that, in broad terms, boys achieved higher levels of performance than girls in all branches of science, and especially so in physical science, although there were exceptions to this finding (Comber and Keeves, 1973). A similar gender difference was reported in the second international comparative study in 1983-84, the gap being greatest in physics and smallest in biology. By the mid-1980s, however, it had become clear that when the test performance in science of boys and girls was investigated in greater detail, a much more complicated picture emerged. For example, tests of the practical skills (performing, reasoning and investigating) of 10-year old students in six countries showed very similar levels of performance by boys and girls, but with girls doing rather better than the boys on 'investigation' items. At age 14, the test scores were again similar for the two sexes but, with both samples, there were significant differences between countries (Doran and Tamir, 1992). In Canada, a survey showed that while boys did better than girls in practical tests that required the use of scientific equipment and laboratory techniques, girls outperformed boys on practical items related to the environment (Bateson et al., 1991).

The Third International Mathematics and Science Study (TIMSS), involving students in Grades 4/5 and 7/8, reported that 'at both grades for nearly all countries, girls and boys had approximately the same average achievement both overall and on the individual tasks' (Harmon et al., 1997).

The research findings relating to gender and assessment have been reviewed by Brusselmans-Dehairs et al. (1997) and the broad conclusion must be that considerable care is needed in interpreting data that represent gender differences in attainment in any curriculum subject. Any interpretation is likely to depend upon the perspective adopted towards how learners learn. Even in those cases where boys and girls are seemingly exposed to the same curriculum, it would be a mistake to assume that, in these circumstances, gender differences in attainment can be attributed to some gender differences in ability. Boys and girls differ, often very markedly, in their pre-school and out-of-school experiences, and these experiences are likely to affect not only the skills and knowledge that they develop but also their perception of the problems that are presented to them and, as a result, their response to them. These pre- and out-of-school experiences are also intimately related to such matters as confidence, interests and expectations which, inevitably, will have a bearing on students' response to, and success at, scientific and technological studies. They are also strongly related to the wider cultural contexts in which boys and girls grow up.

There is evidence that some of the tests that have been used to measure students' attainment in science or technology show a degree of gender and cultural bias. The bias may be linguistic ('his, him or he') and/or be reflected in the portrayal of gender stereotypes, in assumptions about background experience or in the presentation of items in a de-contextualized, abstract form rather than in a more human or social context. A further widespread concern is that many girls may be disadvantaged by an over-reliance on multiple choice or other forms of so-called 'objective' testing. Conversely, girls may be advantaged by forms of testing that allow them to interpret test items in a variety of ways. This is typically the case with extended answer and free-response items and it may explain why a broadening of the range of assessment techniques used in an examination generally leads to a relative improvement in the attainment of girls.

Research has shown that girls and boys may differ in what they regard as significant when they are confronted with a problem and that girls are less likely to abstract issues from the contexts in which they are presented. The following conclusion of Kimbell and his colleagues, based on their studies of technology education within the United Kingdom, resonate with other, science-related, studies (e.g. Murphy, 1998) and almost certainly have a wider geographical validity.

> Girls [appear] to work fundamentally form human needs dealing predominantly with issues. They are often cautious in their entry to a situation, wanting to know how, why and whom it was for . . . Boys, on the other hand, seemed able not only to start into the activity without knowing much, but were prepared to work on specific parts of it without considering the whole . . . possibly to lose sight of it altogether (Kimbell et al., 1991, p. 20).

If assessment is to be fair and equitable, it must be congruent with the curriculum upon which it is based and it must reflect the gender and cultural diversity of those being assessed in ways that allow them the maximum opportunity to reveal what they know, understand and can do.

Policy guidelines

- *Considerable care must be taken in interpreting data purporting to report significant differences in the attainment of boys and girls in science and technology.*
- *The range of techniques used in assessing students in science and technology should be widened as part of a strategy for improving the attainment of girls.*
- *Test questions should place less emphasis upon testing abstract, de-contextualized knowledge and understanding and more upon testing the same knowledge and understanding in a human or social context.*
- *Those constructing and using tests designed to measure student attainment need to be aware of the different forms of bias possible in test instruments and be trained to avoid them by designing gender- and culture-inclusive items.*

Assessment and information and communication technologies

Where the resources are available within an education system, it is possible to present students with tests 'on line' and allow them to answer the test questions in the same way. These test questions may be devised to serve the usual range of purposes, including revision, assessment and accreditation. In many countries, tests also form part of commercially available self-teaching or revision packages.

The use of ICT in this way has a number of advantages:

1. The tests are much cheaper to administer and to mark than conventional paper and pencil tests. There are, of course, capital costs, particularly those associated with the purchase of computing hardware, but online testing is likely to be developed only when such capital costs have already been met for other purposes.
2. It is possible to optimize the use of expertise in test construction and development.
3. The tests can be administered anywhere in the world where the technology allows them to be delivered electronically. This may be particularly important in future international studies of student achievement.
4. There is considerable potential for the development of 'auto-tutorial' schemes of work that make us of interactive and formative assessment techniques.
5. Online testing can make use of video and audio as well as textual material.
6. It is possible to provide students and their teachers with almost instant 'feedback' about test results.

There are also disadvantages, however, in using ICT for testing, of which the following should be noted:

1. Developing the necessary software to permit online testing is expensive. Unless the costs of revising such software are recoverable or can be subsumed in some way, e.g. by large volume sales, there is a risk that the test questions will become out of date.
2. There are limits to the kinds of questions that can be appropriately asked 'online'.
3. Online testing may encourage an 'atomized' approach to learning and understanding and, thereby, to teaching.
4. There can be difficulties of a technical kind stemming from the compatibility of the test software with that available at the test site.
5. Not enough is yet known about how students respond to online testing, e.g. about the influence of the electronic format on students' levels of achievement.
6. In some circumstances, such as tests concerned with accreditation or certification, the need to maintain security can reduce the flexibility that online testing offers.

Policy guidelines

- *Assessment policies need to recognize that ICT has much to offer both formative and summative assessment, in terms of cost, optimizing the use of assessment expertise and the use of video and audio as well as textual material. In some instances, the need for security can limit the flexibility that online testing offers.*
- *The use of ICT to conduct assessments involves substantial hardware and software costs that must be balanced against the benefits to be gained.*
- *Research is needed to establish the effect of electronic forms of testing on students' levels of understanding and achievement.*

References

Aikenhead, G. S.; Jegede, O. J. 1999. Cross-Cultural Science Education: A Cognitive Explanation of a Cultural Phenomenon. *Journal of Research in Science Teaching,* Vol. 36, No. 3, p. 269•88.

Barlex, D.; Pitt, J. 2000. *Interaction: The Relationship Between Science and Design and Technology In: The Secondary School Curriculum*. London, Engineering Council/Engineering Employers' Federation.

Bateson, D.; Erickson, G.; Gaskell, J.; Wideen, M. 1991. *Science in British Columbia*. Vancouver, Ministry of Education.

Bell, B.; Jones, A.; Carr, M. 1995. The Development of the Recent National New Zealand Science Curriculum. *Studies in Science Education*, Vol. 26, p. 73•105.

Bencze, J. L. 2001. Techno-Science Education: Empowering Citizens against the Tyranny of School Science. *International Journal of Technology and Design Education*, Vol. 11, p. 273•98.

Black, P. J. 1993. Formative and Summative Assessment by Teachers. *Studies in Science Education*, Vol. 21, p. 49•97.

Brusselmans-Dehairs, C.; Henry, G. F.; Beller, M.; Gafni, M. 1997. *Gender Differences in Learning Achievements: Evidence from Cross-National Surveys*. Paris, UNESCO.

CERI. 1995. *Decision-Making in 14 OECD Education Systems*. Paris, Centre for Educational Research and Innovation/OECD.

Cogan, L. S.; Schmidt, W. H. 2001. Culturally Specific Patterns in the Conceptualization of the School Science Curriculum: Insights from TIMSS. *Studies in Science Education*, Vol. 36, p. 105•34.

Comber, L. C.; Keeves, J. P. 1973, *Science Education in Nineteen Countries: An Empirical Study*, New York, Wiley.

Commonwealth Secretariat. 1997. *Popularising Scientific and Technological Culture in the Asia/Pacific Region of the Commonwealth. Report of an Expert Group Meeting, Singapore, May 1997.* London, Commonwealth Secretariat.

••••. 1998*a. Popularising Scientific and Technological Culture in African Commonwealth Countries: Report of an Expert Group Meeting, Lilongi, Malawi, February 1998.* London, Commonwealth Secretariat.

••••. 1998*b*. *Popularising Scientific and Technological Culture in the Caribbean, Report of an Expert Group Meeting, St. Ann's, Trinidad, May 1998,* London, Commonwealth Secretariat.

Crossley, M.; Murby, M. 1994. Textbook Provision and the Quality of the School Curriculum in Developing Countries: Issues and Policy Options, *Comparative Education*, Vol. 30, No. 2, p. 99•114.

Doran, R. L.; Tamir, P. 1992. Results of Practical Skills Testing. *Studies in Educational Evaluation,* Vol. 18, No. 3, p. 365•92.

Garnett, P. J.; Tobin, K. 1989. Teaching for Understanding: Exemplary Practice in High School Chemistry. *Journal of Research in Science Teaching*, Vol. 26, No. 1, p.1•14.

Haggis, S.; Adey, P. 1979. A Review of Integrated Science Education Worldwide. *Studies in Science Education,* Vol. 6, p. 69•89.

Harmon, M.; Smith, T.; Martin, M. O.; Kelly, D. L.; Beaton, A. E.; Mullis, I. V. S.; Gonzalez, E. J.; Orpwood, G. 1997. *Performance Assessment in IEA's Third International Mathematics and Science Study*. Boston, TIMSS International Study Center.

Harris, M. (ed.). 1999. *Gender Sensitivity in Primary School Mathematics in India.* London, Commonwealth Secretariat.

Herz, K.; Subbaras, K.; Habib, M.; Rancy, L. 1991, *Letting Girls Learn: Promising Approaches in Primary and Secondary Education.* Washington, D.C., World Bank.

Hodson, D. 1993, Re-thinking Old Ways: Towards a More Critical Approach to Practical Work in School Science. *Studies in Science Education*, Vol. 22, p. 85•142.

Jenkins, E. W. (ed.). 2000. *Innovations in Science and Technology Education. Volume VII*. Paris, UNESCO.

Kimbell, R.; Stables, K.; Wheeler, T.; Wosniak, A.; Kelly, V. 1991. *The Assessment of Performance in Design and Technology*. London, School Examinations and Assessment Authority.

Knamiller, G. W. 1984, The Struggle for Relevance in Science Education in Developing Countries, *Studies in Science Education*, Vol. 11, p. 60•78.

Koblitz, A. H. 1996. Challenges in Interpreting Data. In: H. Moore (ed.), *World Science Report 1996*. Paris, UNESCO.

Layton, D. 1992, *Innovations in Science and Technology Education, Volume IV*. Paris, UNESCO.

Leo-Rhynie, E.; Institute of Development and Labour Law, University of Capetown, *c.*1999. *Gender Mainstreaming in Education: A Reference Manual for Government and Other Stakeholders*. London, Commonwealth Secretariat.

Matthews, M. R. (ed.). 1998. *Constructivism in Science Education. A Philosophical Examination*. Dordrecht, Kluwer.

Matsuura, K. 2000. Speech to the Forum Suisse de Politique Internationale, Geneva, 4th May, 2000. Summarized in: *Educational Innovation and Information*, Vol. 104, p. 1•4. Geneva, International Bureau of Education.

Mschindi, T.; Shankerdass, S. 1998. The Mass Media and Science and Technology Education. In: P. Naidoo and M. Savage (eds.), *African Science and Technology Education into the New Millennium*: *Practice, Policy and Priorities.* Kenwyn, AFCLIST/Juta and Co. p. 197•208.

Murphy, P. 1998. School Science: A Gender Perspective. (Paper prepared for the Nuffield Seminar Series, 'Beyond 2000: Science Education for the Future'. King's College London, 26•27 January.)

National Research Council. 1996. *National Science Education Standards*. Washington, National Academy Press.

Pomeroy, D. 1994, Science Education and Cultural Diversity: Mapping the Field. *Studies in Science Education, Vol*. 24, p. 49•73.

Ramanathan, S. (ed.). 1999. *Popularising Science and Technology. Some Asian Case Studies*. Singapore, Asia Information and Communication Centre/Commonwealth Secretariat.

Reynolds, D.; Creemers, D.; Stringfield, S.; Teddlie, C. 2000. World Class Schools. In: D. Shorrocks-Taylor and E. W. Jenkins (eds.), *Learning from Others*. Dordrecht, Kluwer. p.115•36.

Rollnick, M. 2000, Current Issues and Perspectives on Second Language Learning of science, *Studies in Science Education,* Vol. 35, p. 93•122.

Sammons, P.; Hillman, J.; Mortimore, P. 1995. *Key Characteristics of Effective Schools: A Review of School Effectiveness Research*. London, Office for Standards in Education.

Scanlon, E. 1997. Learning Science On-line. *Studies in Science Education*, Vol. 30, p. 57•92.

Swift, D. 1992, Indigenous Knowledge in the Service of Science and Technology in Developing Countries. *Studies in Science Education*, Vol. 20, p. 1•28.

Tobin, K. G. (ed.). 1993. *The Practice of Constructivism in Science and Mathematics Education*. Washington, AAAS Press.

UNESCO. 1991. *The World's Women 1970-1990 • Trends and Statistics,* Paris, UNESCO.

••••. 1994. *The Project 2000 + Declaration. The Way Forward*, Paris, UNESCO.

UNESCO/CASTME. 2001, *Science, Technology and Mathematics Education for Human Development: Framework for Action Adopted at the International Experts Conference, Goa, India, February 2001.* UNESCO/CASTME.

Wolpert, L. 1992. *The Unnatural Nature of Science*. London, Faber & Faber.