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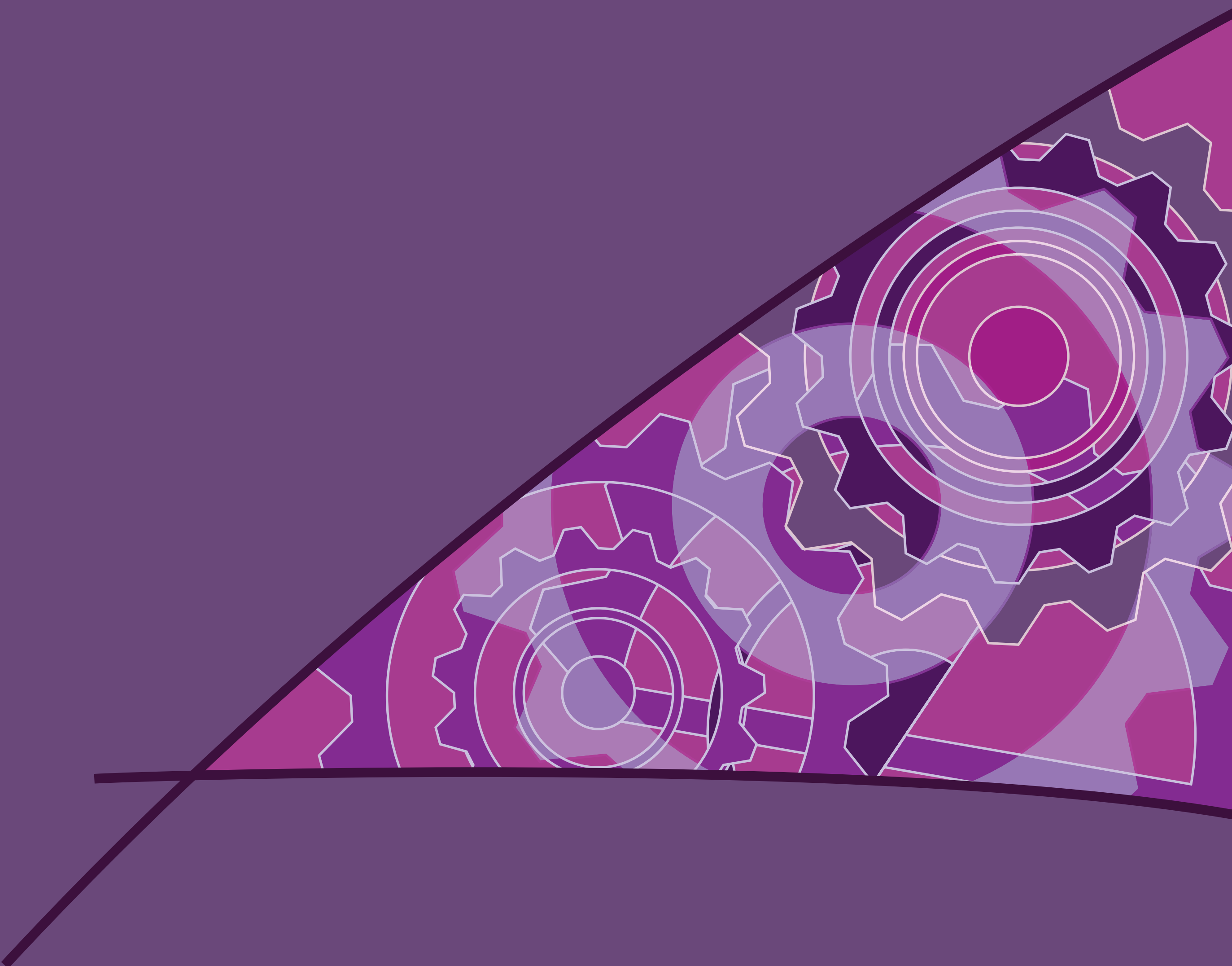
Science Education Policy-making

Eleven emerging issues



SCIENCE EDUCATION POLICY-MAKING

Eleven emerging issues

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Since its earliest days UNESCO has made the improvement of science education a priority. Science educators everywhere have benefited from its support in a multiplicity of ways. A very recent example of UNESCO support is the way it joined with ICASE (International Council of Associations for Science Education) and ASTA (Australian Science Teacher Association) to sponsor the highly successful *World Conference on Science and Technology Education* in Perth in July 2007. More specifically, it encouraged the original production of this document on policy and science education. The local conference organisers, Robin Groves and Elaine Horne, then quite brilliantly ensured its consideration during the Conference and its serious discussion in the Policy Forum that followed. Gary Thomas carefully collated the many comments from the Forum.

Because of the interest shown in these policy issues, UNESCO commissioned the revision of the document. I am personally grateful to the Organisation for this chance to again work with it on this project. Its small group of international reactors made suggestions about some important omissions in the draft and several other improvements. Together they helped greatly to turn a rough draft into a much more considered document.

Executive Summary

The **Perth Declaration on Science and Technology Education** of 2007 expresses strong concern about the state of science and technology education worldwide and calls on governments to respond to a number of suggestions for establishing the structural conditions for their improved practice. The quality of school education in science and technology has never before been of such critical importance to governments. There are three imperatives for its critical importance.

The first relates to the traditional role of science in schooling, namely the identification, motivation and initial preparation of those students who will go on to further studies for careers in all those professional fields that directly involve science and technology. A sufficient supply of these professionals is vital to the economy of all countries and to the health of their citizens. In the 21st century they are recognised everywhere as key players in ensuring that industrial and economic development occurs in a socially and environmentally sustainable way. *In many countries this supply is now falling seriously short and urgently needs to be addressed.*

The second imperative is that sustainable technological development and many other possible societal applications of science require the support of scientifically and technologically informed citizens. Without the support and understanding of citizens, technological development can all too easily serve short term and sectional interests. The longer term progress of the whole society is overlooked, citizens will be confused about what should, and what should not be supported, and reactive and the environment will continue to be destroyed rather than sustained. Sustainable development, and the potential that science and technology increasingly offers, involves societies in ways that can often interact strongly, with traditional values, and hence, making decisions about them involve major moral decisions. All students need to be prepared through their science and technology education to be able to participate actively as persons and as responsible citizens in these essential and exciting possibilities. *This goal is far from being generally achieved at present, but pathways to it are now more clearly understood.*

The third imperative derives from the changes that are resulting from the application of digital technologies that are the most rapid, the most widespread, and probably the most pervasive influence that science has ever had on human society. We all, wherever we live, are part of a global communication society. Information exchange and access to it that have been hitherto the realm of the few, are now literally in the hands of individuals. This is leading to profound changes in the World of Work and in what is known as the Knowledge Society. Schooling is now being challenged to contribute to the development in students of an active repertoire of generic and subject-based competencies. This contrasts very strongly with existing priorities, in subjects like the sciences that have seen the size of a student's a store of established knowledge as the key measure of success. *Science and technology education needs to be a key component in developing these competencies.*

When you add to these imperatives, the possibility that a more effective education in science and technology will enable more and more citizens to delight in, and feel a share in the great human enterprise we call Science, the case for new policy decisions is compellingly urgent. What follows are the recommendations (and some supplementary notes) for policy makers to consider about more operational aspects for improving science and technology education. They are listed under headings that point to the issues within each of these aspects.

In the full document, a background is provided to each set of issues, including the commonly current state of science and technology education. Associated with each recommendation for consideration are the positive *Prospects* that could follow from such decision making, and the necessary *Prerequisites*, if such bold policy decisions are to flow, as intended, into practice in science and technology classrooms.

A. SCIENCE IN SCHOOL AND ITS EDUCATIONAL PURPOSES

Recommendation

A.1 As a first priority, policy makers should consider what are the educational purposes that science and technology education can best provide for students as they move through the stages of schooling

When these specific purposes have been identified and determined, the curriculum designers should work with teachers to select the content, and methods of teaching and learning, and *assessment modes that are most likely to achieve these purposes at each stage of schooling. At some stage in the secondary years, the distinction will need to be made between optional courses in the sciences that prepare for further tertiary study and S&T courses that aim to meet the needs of all students for citizenship in modern society.*

B. ACCESS AND EQUITY IN SCIENCE EDUCATION

Recommendations

B.1 Policy makers should consider, within whatever funding is available, how to maximise the number of students whose science and technology education is in the hands of able science teachers

Quality science learning time, albeit less, is preferable to the damage done by under-equipped science teachers. To achieve this goal of access and equity in S&T education, professional development priority should be given to raising the content knowledge and confidence of the weaker of S&T teachers.

Science Teacher Associations as representative bodies for science and technology teachers have insight and experience of the present problems associated with access to S&T education. They should take practical responsibility for ensuring that their members are equipped to remove any implicit barriers in their teaching that limit access and exclude some groups of students.

B.2 Policy makers should review the participation of boys and girls in S&T education and seek to implement actions that will reduce the explicit and implicit factors that still disadvantage girls in their access to the fields of S&T as interests and careers.

The "Missing Half", namely girls and women in S&T was first recognised in the 1980s. Some progress has been made but there are still real opportunities in most countries to include more of this half of humanity in these great fields of human endeavour.

B.3 Policy makers should consider means of overcoming cultural disadvantages that some groups of students experience specifically in science and technology education.

For example, modern science could be taught as the common powerful knowledge for understanding and operating in the natural world, but other important sources and ways of expressing knowledge about nature should be acknowledged and valued.

C. INTEREST IN AND ABOUT SCIENCE

Recommendation

C.1 Policy makers should make the issue of personal and societal interest about science the reference point from which curriculum decisions about learning in science and technology education are made about content, pedagogy, and assessment

In the early years, the opportunities that science and technology education offer to develop the natural curiosity and creativity of young students should be central to the curriculum's intentions. In the secondary years the role of S&T in the students' worlds outside of school should play a powerful motivating role.

Paralleling these curricular decisions about affect and science, practices that inform students and their parents about the exciting prospects of science–based careers need to be developed in school and among the wider public.

D. HOW TECHNOLOGY RELATES TO SCIENCE IN EDUCATION

Recommendation

D.1 Policy makers should consider mandating that science education should move progressively (as has been done in several countries) towards a real world, "Context-based" approach to the teaching and learning of school science at all levels of the school curriculum

It should be noted that this movement will continue to be built on a strong conceptual base of science, but with the added benefits of deeper learning that enables this conceptual learning to be mastered to the point of being to be **applied** in novel situations.

E. THE NATURE OF SCIENCE AND INQUIRY

Recommendation

E.1 Policy makers should consider what will encourage a better balance between teaching science as established information and those features of science that are referred to as the Nature of Science

Genuine scientific inquiry in school science should be encouraged at all levels as a means of giving students experience of scientific procedures that epitomise the Nature of Science. This experience of scientific inquiry, in its extension to real life situations, will ensure the important interplay of science and technology with other types of knowledge and with values as they are held in society.

F. SCIENTIFIC LITERACY

Recommendation

F.1 Policy makers should consider replacing the generic use of "scientific literacy", as a goal of school science education, with more precisely defined scientific knowledge and scientific abilities, that have meaning beyond school for the students at each of the stages of schooling, for example, lower primary, upper primary, lower secondary, the last years of compulsory schooling and the final secondary years

For students in the later years of schooling consider introducing at least two science courses, one designed for **all** students as future citizens, and the other designed for students with future studies in the sciences in mind.

G. QUALITY OF LEARNING IN SCIENCE

Recommendation

G.1 Policy makers should consider changing the assessment procedures, as critical curriculum factors, in ways that will encourage higher levels of learning as the intended outcomes of school science and technology.

H. THE USE OF ICT IN SCIENCE AND TECHNOLOGY EDUCATION

Recommendation

H.1 Policy makers should consider the cost, provision and maintenance of ICT across the school system in terms of the educational benefit and equity it will bring to schooling in general and to science and technology education in particular.

In revising the curriculum for science and technology, an explicit emphasis will be needed on those aspects of these areas that these ICT tools now make possible.

I. DEVELOPMENT OF RELEVANT AND EFFECTIVE ASSESSMENT IN SCIENCE EDUCATION

Recommendation

I.1 Policy makers should consider how the intentions of the science curriculum for students' learning can be more authentically assessed, both within schools and externally, by the use of a wider variety of assessment tools.

J. SCIENCE EDUCATION IN THE PRIMARY OR ELEMENTARY YEARS

Recommendation

J.1 Policy makers should consider a quite different curriculum for science and technology in the primary years, that engages the considerable pedagogical skills of these teachers, provides their young learners with a series of positive and creative encounters with natural and human-made phenomena, and builds their interest in these two areas of learning.

K. PROFESSIONAL DEVELOPMENT OF SCIENCE TEACHERS

Recommendation

K.1 Policy makers should consider the policy implications (financially and structurally) and the benefits in establishing the provision of ongoing, focussed professional development in science and technology and their teaching, as an essential aspect in the careers of all science teachers

Introduction

In July 2007 UNESCO, ICASE and ASTA sponsored, organised and held a *World Conference on Science and Technology Education* in Perth, Western Australia. At the end of a very stimulating and successful week involving more than 1000 participants from many countries **The Perth Declaration on Science and Technology Education** was issued. It expresses strong concern about the current state of science and technology education worldwide and its failure to play its part in meeting the pressing societal issues of the 21st Century. **The Declaration** is an important development from the earlier contribution of UNESCO (along with ICSU, the International Council for Science) when these two bodies called scientists, activists and policy makers together in Budapest in 1999 at a *World Conference on Science* to discuss the role of science for sustainable development. Out of Budapest came a **Declaration on Science** and a **Framework for Action**.

The **Perth Declaration** argues the case for the educational infrastructure in science and technology education that is essential if the hopes in the **Budapest Declaration** and **Framework** are to be realised in this early 21^{st} Century**.** It calls on governments to respond to a number of suggestions that would establish the structural conditions that will enable science and technology education to fulfil its potential as a key factor in modern societies that are increasingly dependent on, and influenced by science and its applications in technology. The quality of school education in science and technology has never before been of such critical importance to governments. There are three imperatives for this critical importance.

The first relates to the traditional role of science in schooling, namely the identification, motivation and initial preparation of those students who will go on to further studies for careers in all those professional fields that directly involve science and technology. A sufficient supply of these professionals is vital to the economy of all countries and to the health of their citizens. In the 21^{st} Century they are recognised everywhere as key players in ensuring that industrial and economic development occurs in a socially and environmentally sustainable way. *In many countries this supply is now falling seriously short and urgently needs to be addressed*.

The second imperative is that sustainable technological development, and many other possible societal applications of science, require the support of scientifically and technologically informed citizens. Without the support and understanding of citizens, technological development can all too easily serve short term and sectional interests. If the longer term progress of the whole society is overlooked, citizens will be confused about what should, and what should not be supported, and their will be negative reactions to the development. In the process the environment will continue to be destroyed rather than sustained. Sustainable development and a number of other issues involving science and technology can affect societies in ways that often interact strongly, with traditional ways and values. Hence, the making of decisions about them involves moral decisions. All students need to be prepared, through their science and technology education, to actively participate, as responsible citizens, in socio-scientific issues. *This goal is far from being generally achieved at present, but pathways to it are now more clearly understood.*

The third imperative derives from the changes that are resulting from the application of digital technologies that are the most rapid, the most widespread, and probably the most pervasive influence that science has ever had on human society. We all, wherever we live, are part of a global communication society. Information exchange and access to it, that have been hitherto the realm of the few, are now literally in the hands of individuals everywhere. This is leading to profound changes in the World of Work and in what is known as the Knowledge Society. Schooling is now being challenged to contribute to the development in students of an active repertoire of generic and subject-based competencies or capabilities. This contrasts very strongly with existing priorities in subjects like the sciences that have seen the size of a student's a store of established knowledge as the key measure of success. *Science and technology education needs to be a key component in developing these competencies in students for the world of work and for living more generally.*

When you add to these imperatives, the possibility that a more effective education in science and technology will enable more and more citizens to delight in, and feel a share in the great human enterprise we call Science, the case for new policy decisions is compellingly urgent.

This urgency applies differently from country to country, but it applies to all, regardless of their state of development. It is now very evident that in many of the more developed countries there is a downturn in interest among students in relation to both science-based careers and to science as field of lifelong interest. The former threatens the society's economy and health. The latter means that the prospects are not good for personal well-being, and for improving the awareness the public ought to have, in democracies trying to find solutions to the pressing personal, social and global problems that involve science and technology.

Countries, whose societies can be described as '*in-transition*', face similar problems, but within the even bigger ones of trying to make science and technology education more accessible when there are not enough qualified teachers. Jaya Earnest and David Treagust (2007) in **Education Reform in Societies in Transition** have put together a timely set of essays that does give priority to these countries' science and technology education, so often obscured by the flood of writing that comes for the practised authors in the developed countries. In each case the importance of sound policy making is evident.

If science educators, like those at the **World Conference**, are to be advocates of policy changes for their area of interest, it is first important that they begin by learning some important lessons from the past about science education reform. In the 1960/70s a great deal of money and human effort went into reforming the curriculum for school science in a number of countries, after it been left unchanged for many years because of economic depression and World War II. Substantial funds were provided to develop supporting materials (texts, practical manuals, teachers' guides, etc.) for exciting new ways to teach school science. In the years that followed, the effect of these major investments was monitored in various ways. Overall the uptake of these new possibilities in their home countries was somewhat disappointing. Indeed, these materials, with varying degrees of adaptation, were more universally adopted in some other countries. The projects had considerable scientific status thanks to the scientists involved, but the commitment of educational policy makers for their implementation was not obtained and so it remained voluntary. Enthusiastic science teachers in innovative schools took advantage of them, but the majority was unaffected.

One way to explain this limited impact is that these developments occurred as if school science takes place in a political vacuum. This naivety failed to recognise that the curriculum for school science is a highly contested matter. Different stake holders can perceive quite differently the merits and demerits of the existing curriculum and a proposed new one, colourings their response when they reach the policy levels that count. A further problem of dissociating curriculum development from policy was that the innovations for changing science education often became available when schooling, as a whole, was facing quite other urgent issues and demands. The **Case Studies of Science Education CSSE**, (Stake and Easley, 1978) illustrated how the US innovatory materials struggled for recognition at the levels of schools and school districts, because of priority differences. At the individual classroom level, quite unanticipated factors also could produce slippage between what was intended and what happened in practice.

In the years since, this mistake of forging ahead at the enthusiast level for better science education has often been repeated, without incorporating the key policy makers at the levels of decision implementation and practice. On other occasions, however, there are many good examples of partnership between the policy makers and the innovative science educators that have led to improved science education. Such a partnership of responsibilities is essential if the realities of the wider educational scene and of science and technology education, as a special component, are to be optimised.

When the importance of working step by step with the key policy makers is recognised, science educators must then have good grounds for establishing in these persons' minds that there is a need for change in current science and technology education practices. This need for change should be justified by the provision of evidence, that the present policies and their outworking in practice are failing to meet widespread current intentions for science education. Finally, science educators should produce some evidence that the changes being advocated will achieve the intentions for science and technology education. It is not easy to provide concrete evidence for practices that are not yet widespread, so the evidence must be drawn from cases that are indicative rather than definitive. Nevertheless, if the evidence against the current practices is sufficiently well assembled and kept in the forefront of the discussions, the case for new policy can be built.

The *Associations of Science Education* (national science teacher associations), that make up the membership of the *International Council of Associations for Science Education (ICASE)*, co-sponsored the **World Conference** in Perth. Their traditional role has been the support of their member science teachers, and they have a proud history of fulfilling it. Hitherto, in many countries they have not been actively engaged in the more political roles of lobbying for more funding and better conditions for science and technology education. ICASE has been encouraging its member associations to see these actions as means of more substantially supporting their member teachers, and at the same time of serving society by better use of the expertise of their members. There is no doubt that the insights and experience of these associations members are basic ingredients for the analyses of the current situation in science and technology education that are key steps in making new policy and its implementation in practice. The Perth Declaration is a major step in this new direction for ICASE and its science teacher associations.

Science education researchers have all too often tended to treat *Policy, Practice* and *Assessment* as discrete areas for study. Although an **Implications** section commonly appears at the end of research reports, it is usually about further research. Implications for practice are sometimes discussed, but what the research means for science education policy is rarely mentioned. There are, however, some excellent exceptions, and these have been associated with real advances in curriculum structure and classroom pedagogy. Research can contribute much better when all three of these areas come together in some orchestrated fashion, and educational authorities should deliberately encourage this conjunction to happen more often.

Because their studies of particular practice in science education are so detailed and time consuming, researchers have a bad habit of assuming their findings will have much wider application than is warranted. The reverse of this is when they are reluctant to make suggestions for new policies or comment on innovations for practice, because these have not been fully and directly researched. Policy advice has to work on probabilities or likelihood of success. The gathering together of established gains in practice from a number of studies is one way researchers can more usefully contribute to policy.

Currently, many countries are participants in two large scale comparative studies of student achievement in science. The IEA and the OECD both claim that their projects are designed to assist participating countries with their policy interests. Certainly much data are collected about the students' achievement on tests that reflect the very different interpretations of science learning in TIMSS and PISA. Both projects also collect data on a large number of contextual constructs that include school characteristics, teachers, science classrooms, students' family backgrounds, gender, interest in science and science education, etc. This second set of data is justified because it is claimed to have potential for interpreting the achievement scores. In this way, it is to be hoped that the participating countries are finding these studies do have the policy usefulness that their designers intend.

In the eleven sections that follow, the issues around a number of operational aspects for improving science and technology education are discussed. A ***Background*** is provided for each set of issues, and this includes the commonly, current state of science and technology education. This is followed by a **Recommendation** for a policy change that could be expected to lead to improvement. (A supplementary comment is sometimes added.) Some of the related evidence for this recommended change is included in the ***Background***. Each recommendation is followed by a number of positive *Prospects* for students and teachers that could be expected to follow if such a policy decision was made. Finally, under *Prerequisites,* some of the supporting conditions that would need to be changed are listed. *Policy decisions may be the starting point for better practice, but without change to existing constraints and other factors, too little of this better practice will be implemented and general improvement will not be achieved.*

ISSUE A: SCIENCE IN SCHOOLING AND ITS EDUCATIONAL PURPOSES

Background

Science as a component part of compulsory school education is, in one sense, so obviously necessary that it requires no more statement of purpose than its title. After all, we all live in societies that are increasingly influenced by science and its technological applications. Thus, a society's schooling programmes that leaves its students unaware of the strengths and limitations of science and technology would indeed be reprehensible. These statements are already, however, beginning to express more specific purposes for school science. The Perth Declaration begins with an affirmation of the importance of science and technology for *sustainable, responsible* and *global* development. It sees science and technology education as the essential means of bridging of the gap between these roles for science and technology and the public's active understanding and participation in them.

In relation to the presence of science in schooling, it is important to be reminded how science historically entered schooling. It was not for the reasons just mentioned, but to simplify the transition from senior secondary schooling to university science and technology based studies for a small elite of students who were to become the next generation of scientists, engineers and medical practitioners. The science content and pedagogical experiences that were, and is, useful to learn for this important but limited purpose is not necessarily the ideal educational means when other educational purposes for science and technology education are also priorities.

As science over the last 100 years has slowly been given a place in the curriculum of the earlier years of schooling, its original purpose has tended to remain the predominant determinant of the content and means of teaching and learning. By the 1990s science and technology were recognised in many countries as worthy of a place from the first to the last years of schooling. In recasting the curriculum to include science and technology, the content for learning that was listed as vertical strands, stretching across all these years, still carried the strong conceptual tone that characterised the science preparation of the elite group when they were the sole concern and purpose of school science. Science, in this academic sense of its meaning, had been assumed to be capable of serving the very different outcomes or purposes that the totality of contemporary students now needed from studying science and technology. These strands of content certainly on paper gave a sense that a sequence of learning was occurring and for many secondary science and technology teachers these strands were familiar from their own specialised studies. On the other hand, they were threatening to many primary teachers whose background in the sciences was much less.

For many students the evidence is that these long strands were like ladders of increasing difficulty, not offset by interest and relevance. In a number of countries there is evidence to suggest that fewer students than in the past are persisting with enthusiasm to climb these ladders of science. Getting the balance right between the purposes of enthusing enough students to go on to scientific and technological careers and of giving all students an interest in, and enough knowledge of S&T to appreciate the importance of science and technology in society, is perhaps the major S&T educational issue facing all countries today. It is a balance between two reference points for S&T education. One is the world of Science itself as a specialist enterprise. The other is the myriad aspects of modern life and thought in which SD&T play or could play a determining or controlled role. Resolving this balance will be different depending on a country's retention rates of students, the resources available and its societal demands, but its resolution is critical for countries at all stages of development.

Douglas Roberts in Canada, as long ago as the 1980, provided a fresh way to approach this issue when he drew attention to the idea that there are multiple educational purposes that school science can usefully play. Different purposes, he argued, will best be served by distinctive content for learning, linked to appropriate experiences of teaching, learning, and assessment. Roberts claimed that both teachers and students will be confused about science, if too many purposes are being attempted at the same time. So he suggested the novel idea that different purposes might be emphasised at different stages of schooling – a horizontal view of the years of schooling, rather than the vertical one above that was so commonly espoused in the 1990s. A corollary of his suggestion is that particular groups of students, particularly in the later years of schooling when their personal life worlds, interests and future intentions, are diverging, may be better served by different courses of study in science and technology.

The wisdom of Roberts' comments becomes clear when the list of aims for a school science curriculum are examined. A common one about *equipping young persons to participate in the big socio-scientific issues of today (global warming, cloning, embryonic stem cell use, toxic waste disposal, etc.)* makes good sense in the later compulsory tears of secondary education. This purpose makes little sense in the early primary years compared with *engendering science as a means of stimulating curiosity and appreciation of the beauty, wonder and curiosity about the natural world* - a more tangible and important purpose that would lead to an excellent foundation for these younger learners to build on in their later years of schooling. Being encouraged to ask questions about natural phenomena in this way becomes the base from which to learn which questions are scientifically investigable and what such investigation involves.

Recommendation

A1 As a first priority, policy makers should consider what are the educational purposes that science and technology education can best provide for students as they move through the stages of schooling.

When these specific purposes have been identified and determined, the curriculum designers should work with teachers to select the content, and methods of teaching and learning, and assessment modes that are most likely to achieve these purposes at each stage of schooling.

At some stage in the secondary years, the important preparatory studies in science and technology for further tertiary study should continue to be available as an optional study alongside the courses to meet the S&T for Citizenship purpose that all students need prior to the end of their schooling.

Prospects

Such a horizontal view of schooling and students' interests makes particular sense to teachers in the primary years, and has the prospect of increasing science's relevance for students .

S&T learning is not tied so sequentially tied to a single purpose, and hence students can "re- enter" it and find renewed enthusiasm via its now different purposes.

Prerequisites

Secondary science teachers will need considerable p.d. help in reconceptualising this restructuring of the curriculum for science, with its shift in content from academic science to science in application in the real world of students, but they will find reward in the response of their students. Support materials will need to be developed for teaching in these new directions. Context-based assessment that reinforces the new intentions must be developed along with the skills of teachers to use it formatively in their teaching..

ISSUE B: ACCESS AND EQUITY IN SCIENCE EDUCATION

Background

Getting clear the purposes of science and technology education may be the first step towards meeting the challenges in the Perth declaration, but a second step is to ensure that the curricula that follow are open to all students in terms of access and equity.

In many countries there are still restrictions that prevent many students having access to quality science education. In some cases this is part of the more general issue of access and equity to schooling itself, but in other cases it relates to unequal access for some specific groups or to more subtle equity issues.

In countries where primary schooling only is the level that is available to all, policy makers must direct their attention to resources and assistance to their primary teachers so that they can include basic science and technology in the primary curriculum. There are so many useful S&T notions and practices that these young students can then feed back into their families and carry with them into their lives in society. An example of how focussed teacher support can overcome extreme limitations of physical resources for teaching science is to be found in a beautiful book, One Pencil to Share, written by a number of South African primary teachers in rural settings. It is in a number of these countries also that social traditions and conditions often still act to the disadvantage of girls gaining this all important level of education. Policy makers need to offer family support that enables the full participation by girls in primary education.

The OECD Global Science Forum points out that girls in tertiary education has been increasing but not in the fields of S&T. The ROSE project data shows that there are clear differences between boys and girls interests in science education in both developing and more developed countries. In both cases the curriculum content and the dominant pedagogy are still generally biased towards the boys' interests of boys, thus implicitly limiting access to girls. In more affluent countries, after 20 years of the *Girls and Science and Technology (GASAT)* movement, there are a variety of ways in which equity is still an issue with respect to science and technology education. Beyond the compulsory years, curriculum options mitigate against girls continuing with science studies, for example, the time tabling of foreign languages and other humanities can preclude continuing study of the physical sciences, and thus, girls choices of education and careers beyond school are severely limited.

Science and Technology education with their traditional expectations of content and pedagogy very largely ignore the cultural differences of some minority groups in schooling. Difference in language use in these groups compared with the dominant groups can result in the language of school science being a source of disadvantage. Attention to the particularities of science descriptions and writing is needed to assist these students' access.

More generally, government policies often compound educational disadvantage geographically or by encouraging private schools. Too many S&T classes are still taught by teachers without strong backgrounds in these fields. Their lack of scientific knowledge, skills and confidence has been shown to reduce their students access to a rewarding S&T education. Instead of focussing the resources for professional development on long term remediation of these teachers' deficiencies, these resources are too often short term programmes, that are of more benefit to the already more able teachers of S&T and the schools in which they are concentrated. Equity is not addressed and the educational system thus compounds the advantage that students from high family socio-economic status bring to it.

Cultural dissonance

Cultural differences are another case where barriers to access and equity occur. There is now such a body of research studies into the problems associated with the participation of indigenous students in science and technology education, that this case warrants its own reference. It is noticeable in African countries, and in others like New Zealand, Canada, USA, Australia and Norway, that indigenous students participate less successfully than students from the dominant social backgrounds. The family culture of these indigenous students, ironically, includes a great deal of detailed knowledge about the natural world that has been acquired over many generations of careful observation and experiment. This knowledge, and the values associated with it, is often expressed in ways that are very different from those used in modern science. It is also acquired in ways that are very different from the teaching context of schooling. Accordingly, the teaching of modern science, as if it is the only source of knowledge about the natural world, can be a contradiction of knowledge and values that are very important to students in these cultural groups. When this difference is not acknowledged, it can be a real access barrier for these students.

Recommendations

B.1 Policy makers should consider, within whatever funding is available, how to maximise the number of students whose science and technology education is in the hands of able science teachers.

Quality science learning time, albeit less, is preferable to the damage done by under-equipped science teachers. To achieve this goal of access and equity in S&T education, professional development priority should be given to raising the content knowledge and confidence of the weaker of S&T teachers.

Science Teacher Associations as representative bodies for science and technology teachers have insight and experience of the present problems associated with access to S&T education. They should take practical responsibility for ensuring that their members are equipped to remove any implicit barriers in their teaching that limit access and exclude some groups of students.

Prospects
Real progress would be made towards quality S&T education for all. Hitherto untapped student potential for S&T nation building will be realised. An increasing number of students having access to quality science teaching and learning. More teachers capable and confident to deliver quality S&T education.

Prerequisites
A serious commitment to the quality of S&T learning as the priority criterion in resource distribution and programmes that are addressing the expansion of education.

Acceptance by Science Teacher Associations of their role in improving student access to S&T education.

B.2 Policy makers should review the participation of boys and girls in S&T education and seek to implement actions that will reduce the explicit and implicit factors that still disadvantage girls in their access to the fields of S&T as interests and careers.

Prospects
The "Missing Half", namely girls and women in S&T was first recognised in the 1980s. Some progress has been made but there are still real opportunities in most countries to include more of this half of humanity in these great fields of human endeavour. S&T education that encourages and engages both boys and girls can lead to great benefits for any country

Prerequisites
A searching study of the obvious, and not so obvious, ways in which girls are still discriminated against with respect to access to S&T education. Changes will be needed in structural conditions that reinforce this lack of gender equity, and professional development must continue to make curriculum designers, and teachers aware of how gender inequity can be reduced.

B.3 Policy makers should consider means of overcoming cultural disadvantages that some groups of students experience specifically in science and technology education.

For example, modern science could be taught as the common, powerful knowledge for understanding and operating in the natural world, but other important sources and ways of expressing knowledge about nature should be acknowledged and valued.

Prospects
Such cultural recognition can enable indigenous students to engage with modern science, without feeling they must abandon their cultural heritage.

Pre-requisites

Many science teachers will require professional development help to appreciate and respect this indigenous knowledge. Their teaching and learning strategies will also need to be extended in order to optimise the benefit with indigenous students.

ISSUE C: INTEREST IN, AND ABOUT SCIENCE

Background

Since 2000, study after study has made very clear that there is an alarming crisis in relation to students' interest in science, either as a possible future career, or as an intrinsic interest that will continue after school. The list of countries that have recorded concern about this matter is now very long, especially among the more developed ones. This lack of interest is due to a complex of factors including societal ones that are beyond schooling. For example, ignorance about employment prospects in science and technology, and their unfamiliarity as areas to many parents, play a role as does the positive and negative images of science promoted by the media. Within education itself, there is mounting evidence that the experience of school science is, by itself, contributing to this malaise among students (internationally: *ROSE* project, *TIMSS*, *PISA*; and numerous national studies). It is urgent that educational policy makers address the lack of engagement that so many students experience in school science and technology education. It is this aspect of the larger issue that science educators have some hope of remedying.

The international studies report a confusing lack of correlation between students' achievement in school science and their interest in the subject. A large national study found students from Years 6 to 9 registering a decline in interest in most subjects, but only science and mathematics were seen to lack intrinsic worth.

The following are common features of being in science classes, that directly contribute to low interest, when students of 15 compare science with other subjects.

- Science teaching is predominantly transmissive.
  As a student, learning science is simply a matter of being like a sponge, and soaking up this knowledge as it comes from the teacher or from the textbook.
  Science knowledge is dogmatic and correct. There are no shades of grey about science.

- The content of school science has an abstractness that makes it irrelevant.
  So much what is taught in science is uninteresting because it is not related to our everyday lives. Science in films and in the media is often exciting, but that is not an aspect of the science we hear about do in school. There are science topics that would be interesting but these are not in our school curriculum.

- Learning science is relatively difficult, for both successful and unsuccessful students.

Science is more difficult than a number of the other subjects, and especially compared with ones I can choose in the later years of schooling.

- Hence, it is not surprising that many students in considering the senior secondary years are saying:
  Why should I continue studying science subjects when there are more interactive, interesting and less difficult ones to study?

Furthermore, there is now recent evidence suggesting that students are forming decisions against science in the later primary years, long before careers advice is offered in schools.

In order to highlight these disturbing issues, the PISA project in 2006 added two affective aspects of science, *personal interest in science* and *support for science i*n its target statement of scientific literacy, and included items to measure these in its main achievement test (see PISA 2006 Framework, OECD). This was a deliberate attempt to indicate that *personal and social interest in science* that should be intended and expected learning outcomes from school science. In December 2007, the international and national results from this project across more than 50 countries will add considerably to our knowledge of the issue.

Aikenhead (2005) in his recent book, **Science Education for Everyday Life** has contrasted *'traditional school science'* with what he terms *'humanistic school science'*. The depersonalised character of the former contrasts with the latter's explicit acknowledgement of Science as one of the great human enterprises in the history of civilisation. Each concept and principle in science textbooks are recognised to be the result of great human drama. In the former, motivation is a factor good teachers add. In the latter, teachers are aided because the content is set in intrinsically motivating contexts. Science, when applied in society as ideas or technologies, is not simply a technical solution, but it becomes a change agent for society, and in human lives. Teaching *Science as a Story* is a new pedagogy in some recent science curricula. Stories, involving characters, plots and their resolution, have been a universal way in which societies educate their young, but it has been virtually ignored in school science. Aikenhead's book's sub-title is *Evidence-based practice*, and in it the author argues that when school science takes on the features of *humanistic science*, there are positive cognitive and affective responses from students and their teachers.

Recommendation

C.1 Policy makers should make the issue of personal and societal interest about science the reference point from which curriculum decisions about learning in science and technology education is made about content, pedagogy, and assessment.

In the early years, the many opportunities that S&T education offer to develop the natural curiosity and creativity of young students should be central to the curriculum's intentions. In *the secondary years the role of S&T in the students' worlds outside of school should play a powerful motivating role.*

Paralleling these curricular decisions about interest and science, practices that inform students and their parents about the exciting prospects of science–based careers need to be developed in school and among the wider public.

Prospects

More students will develop an interest in science, and more will consider scientific and technological careers.

Pre-requisites

Pre-service science teacher education should begin to remedy its students' lack of stories of science. Professional development of S&T teachers should give priority to how real world contexts can be used in their teaching to optimise cognitive and affective learning outcomes.

Formative and summative assessment modes that encourage affect-including cognition of science and technology will need to be developed.

ISSUE D: HOW TECHNOLOGY RELATES TO SCIENCE IN EDUCATION

Background

In keeping with earlier UNESCO/ICASE recognition in 1994 of the importance in society of the link between science and technology, the **Perth Declaration** reiterates their inter-relatedness. This is an important corrective to the separation between science and technology in schooling that occurred in a number of national curricula that appeared in the 1990s. In these curricula, the title, *Technology*, was used to give new recognition was to design, problem solving and making, that had been practical features of subjects like *Craft and Design, Woodwork, Metalwork, Home Economics, Industrial Arts ,etc.* Already, the potential that computers had to transform these hands-on subjects more than justified that these practical features should appear as a new key Learning Area. In this sense, the new subject, Technology was quite a separate field from Science and science teachers are not usually its teachers. The common use of the term, technology, as applications of Science, does however, very properly belong within the area of science teachers. In this document, this is essentially what is meant by 'science and technology education'.

Entitling this new subject with the word, "Technology" was, however, quite disastrous for the developments that had become to appear in science education. In the later 1980s innovative science educators were developing materials that enabled science teachers to include applications of science in the form of technologies in their teaching. Projects, such as ***Science and Technology in Society (SATIS), PLON*** (for physics),

LORST, Salters Science, were thus providing teachers with a means of bridging the teaching and learning of science to the modern societies in which their students live. The movement in science education towards this link between science and its technological applications was so strong that it became known as Science-Technology-Society (STS). The STS movement re-awakened science teachers to the fact that the concepts they were teaching owed their existence in science to the fact that they were powerful links between natural phenomena that initially may have seemed quite distinct. The more developed STS projects used the slogan, *Concepts in Contexts*, to express a powerful teaching and learning strategy. This was the recognition that the meaning of the concepts in science education will be learnt at a deeper level if their role across different familiar natural contexts is brought out. Conversely, the students' sense of confidence and familiarity with these familiar everyday contexts will be strengthened by their conceptual understanding.

The designation (see above) of some formerly practical subjects as *'Technology'* in the emerging national curricula brought this movement to an unexpected halt. It immediately shut off the STS direction in which school science education was so promisingly moving. Without the Technology bridge to Society, the Science component of the trio reverted to an emphasis on science concepts, without the contexts of application that could give them a reality of meaning to students. Furthermore, these national reforms applied to all the years of schooling so that this essentially abstract content in distinct disciplinary strands became what was to be learnt in school science at all levels.

By the end of the 1990s, the failure of these new curricula to attract students to science as careers or to science as a life long interest was beginning to appear. Conceptual learning in science was very largely at a shallow level of information recall as teachers struggled to cover the long lists of science content that were set down for each year in these new curricula. There was an endless contradiction between teaching conceptual learning to the depth at which it becomes powerful knowledge, and covering the syllabus in its entirety for the shallow level of learning that science assessments tended to demand.

BEYOND 2000, a report published in England and Wales late in 1998 recommended a reduction in detailed content in order to deepen the level of learning and urged the re-association of science and technology as an important means of improving student interest, science's relevance, and its conceptual meaning. The emergence in these years of exciting new scientific fields with titles like Gene Technology, Bio-technology, Nano-technology and Materials Technology, highlighted the nonsense of the educational decisions that separated Science and Technology as distinct areas of schooling.

Recommendation

D.1 Policy makers should consider mandating that science education should move progressively (as has been done in several countries) towards a real world, "Context-based" approach to the teaching and learning of school science at all levels of the school curriculum.

It should be noted that this movement will continue to be built on a strong conceptual base of science, but with the added benefits of deeper learning that enables this conceptual learning to be mastered to the point of being to be applied in novel situations.

Prospects

Deeper level of conceptual science learning enables transfer of learning to novel contexts.

An increase in student interest when the enabling contexts are well chosen.

Real world contexts make possible a greater variety of scientific investigations.

A better appreciation of the strengths and limitations of science since real world contexts are never purely scientific.

Pre-requisites

Acceptance that fewer details in science topics will be covered in order to strengthen learning of what are identified as important ideas and explanatory frameworks in science.

Disciplinary trained science teachers will need professional development with the interdisciplinary aspects of S&T real contexts and the more open-ended nature of investigating them.

Pre-service science teacher education should be asked to move to a context-based curriculum for content and pedagogy.

ISSUE E: THE NATURE OF SCIENCE AND INQUIRY

Background

If the second resolve in the **Perth Declaration** about 'increasing students' interest in and recognition of the roles of science and technology in society' is to be achieved, there is no doubt that how problems are identified, investigated, and solved in Science must have a prominence in the curriculum. Students, who are seen as successful in school science, know many bits of scientific information, but they often have little or no sense of the path this knowledge has been through in its establishment, and what might lead to it changing. Without a good sense of these aspects of the strength and limitation of scientific knowledge, they do not have the capacity to establish the worth of the claims that are regularly made in the name of science or the many forms of pseudo-science. The students have been deprived of what gives Science the power and influence it has or should have in their lives and in society, and where its boundaries of influence lie. Furthermore, the students are ill equipped to relate the science aspects of S&T issues in the real world to those other aspects - social, economic, aesthetic, political, etc. - that are also so often present.

Science is distinguished from other fields of knowledge by its use of empirical methods for establishing its knowledge claims about the natural world. These methods provide objectivity to Science's claims that give them professional credibility that transcends the person of the scientist, his/her laboratory, and indeed the particular national resource base carrying out the investigation. School science has often given low priority to this distinguishing feature, paying only lip service to Science's empirical nature. We have glibly used the word "*inquiry*" in our curricular rhetoric, but refer to it rarely in teaching the established content knowledge of the sciences. Depending on the wealth of our countries, we expend different amounts, often very large, on ensuring there are opportunities for hands-on practical activities in science teaching and learning. Most of what is done with these facilities is often simply following a recipe to achieve a result that is already present in the science textbook. Truly open-ended investigations that represent real scientific inquiry are still very rare in school science. The local and international examinations that are used to assess science learning are mainly concerned with the recall and simple application of the taught established knowledge that is in the sciences. Comparable attention is lacking about how this knowledge has been established and how it should be built in to further investigations of S&T problems.

In recent years, there has been a push to achieve a better balance in school science education between established scientific knowledge and knowledge about science's procedures. The latter is often referred to as the *Nature of Science*, but what this term means has not been well clarified to science teachers. Is it another name for Scientific Method(s)? Is it a revival of the set of so-called processes that was strongly encouraged in the primary years from the 1960s to the 1980s? Is it another name for the strand introduced in a number of national curricula in the 1990s under headings like *Working Scientifically, Habits of Mind, or Scientific Investigations?* Is it what is being suggested in the 2000s as *Science by Doing*, or *Science at Work, or Science as a Way of Knowing?*

One of these terms, *Working Scientifically*, was used in England and Wales in 1991 for a single "process strand" which was initially proposed to be two separate strands, *"Exploration of Science"* and *"Nature of Science"*. The former was about the common procedures in science that underlies "a fair test" or for investigating the relations between variables. The latter sought to project an image of Science as a historically evolving field of human knowledge that is responsive to cultural and social influences. The eventual single strand was essentially the former with almost nothing of the latter. Nevertheless, the mutual interactions between science, culture and society, that were hinted at in the latter strand, are aspects of the Nature of Science involving value issues that school science has been reluctant to consider, particularly in more developed countries. This does not mean these issues do not exist, and a number of more developing countries which include *Values Education* as part of their curriculum, are better placed to extend the teaching of the Nature of Science in this direction.

In trying to clarify Nature of Science the OECD's PISA project found it useful to distinguish between Knowledge ***of*** Science and Knowledge ***about*** Science. Knowledge of Science refers to knowledge of the natural world from the major fields like physics, chemistry, biological science and Earth and space science. Knowledge ***about*** Science refers to knowledge of the procedures of scientific inquiry, the goals of scientific explanation and use, and of the relations between science and technology and their complementary roles in society. For 2006, PISA Science chose to focus, for its testing of 15 year olds, on three scientific procedures, *Using scientific evidence, Identifying scientific issues, and Explaining phenomena scientifically*, each one of which is a mix of Knowledge ***of*** Science and Knowledge ***about*** Science. This mixture is a consequence of the reality that Knowledge of Science and Knowledge ***about*** *Science are* integrally related. Knowledge ***about*** Science always involves Knowledge ***of*** Science. In a very important paper, Driver and Millar (1987) argued that the separation that had been made in school science curricula between science content and science processes is a false dichotomy. It is not supported in science itself, or by the learning of science, or by the history and philosophy of science.

Another idea that could be helpful in clarifying the *Nature of Science* in an operational sense for school science teachers is the suggestion that understanding a discipline (like Science) is to be able to use its forms of discourse. Some important discourses in science are *Asking investigable questions, Describing a phenomenon, Arguing to establish a scientific claim, and Explaining macro-level behaviour by means of a more micro-level ideas.* These then are useful and important abilities for science teachers to demonstrate and to regularly provide opportunities for their students to practice them.

Recommendation

E.1 Policy makers should consider what will encourage a better balance between teaching science as established information and those features of science that are referred to as the Nature of Science.

Genuine scientific inquiry in school science should be encouraged at all levels as a means of giving students experience of scientific procedures that epitomise the Nature of Science.

This experience of scientific inquiry, in its extension to real life situations, will ensure the important interplay of science and technology with other types of knowledge and with values as they are held in society.

Prospects

Students are more likely to feel a sense of control or empowerment in relation to S&T.

Deeper conceptual learning is likely to result because of the integration with their sources in science and their applications in society.

Students will be better prepared for the values issues that are part of so many S&T issues in society.

Pre-requisites

Since the majority of science teachers have not practised as scientists, mentoring programmes that enable them to gain some experience of actual scientific investigations will need to be established.

Processes will need to be put in place to ensure that this changed balance in the science curriculum occurs in school science classrooms, and to reinforce it via assessment practices.

Pre-service science teacher education should include a "work experience" component that provides a realistic experience of open-ended scientific investigations.

ISSUE F: SCIENTIFIC LITERACY

Background

In some respects what is important about scientific literacy has been included in the five issues already discussed. However, since the term, *Scientific Literacy* became very popular in the 1990s as a new slogan for the intended purpose of school science, it has too often been confusing, rather than clarifying. Accordingly, it does need to be addressed directly.

Scientific literacy had a more operational ring about than *Science for All*, the slogan of the 1980s, which it replaced. It also seemed to link science education, now that it was becoming mandatory in primary schooling, with the high status and priority that the literacies of *Language* and *Number* enjoy in those years.

Despite its operational ring *"scientific literacy"* did not have an obvious definition. Unlike language and number that have always been established priorities in the primary years of schooling, science had no such history of establishment in these years. There was no obvious counterparts in science to the basics of reading, writing and number operations. Furthermore, no one was suggesting that successful completion of science learning in the primary years would be a reasonable indicator of a country's scientific *literacy*, as is the case for the literacies of language and number.

Scientific literacy was soon being associated in a number of countries with an amount of content for learning in school science that was patently absurd. For example, the *Benchmarks of Scientific Literacy* that were promoted by AAAS (1993) in USA, exceeded what had hitherto been the science content for the academic groups of secondary students who had chosen to specialise in the sciences. One reason for this excessive content was the extension of a disciplinary structure for science to all the years of schooling. At each year level, there was content from *Biology, Chemistry, Physics,* (plus *Earth Sciences*) together with one or more process strands like *Working Scientifically, or Habits of Mind. Scientific literacy* was being interpreted as a fully rounded education in the sciences, rather than being some sort of basic level of learning in science.

Curricula that set this very high level of science learning as expected for all students must be a factor in the serious decline of interest in science to which reference has already been made.

A breakthrough from this unsatisfactory interpretation of scientific literacy came when several countries initiated a curriculum of secondary level courses that differentiated the science education needs of future citizens needed (that is, all students) from the science education for the minority group who have an interest in scientific careers. The idea of *Science for Citizenship* has been helpful in the re-defining scientific literacy for the all students in the last years of compulsory schooling. A recent example of such a curriculum is the GCSE Science subject in England and Wales that is the mandatory component of a suite of science subjects developed by ***21st Century Science*** at York University in England. The optional subject, *Additional Science*, caters for those students who wish to go on with disciplinary sciences in later years, and *Applied Science* for those wanting to pursue Science's applications of science in detail.

The OECD's PISA (Science) project was charged with providing information to educational systems about how well all 15 year old students are prepared for the ways Science occurs in the lives of citizens and societies in the 21st century. Because of this specific focus, the PISA (Science) project has been free to define *scientific literacy* in terms that reflect *'the preparedness'* it is trying to measure. For its testing in 2006, it has done so by defining three scientific competencies and two affective constructs that students are expected to apply to unfamiliar real world situations involving science and technology. The three competencies have been described in Section E above. The PISA project illustrates the fact that scientific literacy does not have a fixed meaning or definition. Nor is it a singular notion. Each purpose for science education can well have its own set of scientific literacies.

Recommendation

F.1 Policy makers should consider replacing the generic use of "scientific literacy" as a goal of school science education with more precisely defined scientific knowledge and scientific abilities, that have meaning beyond school for the students at each of the stages of schooling, for example, early primary, later primary, lower secondary, last compulsory years, senior secondary.

For students in the later years of compulsory schooling consider introducing at least two science courses, one designed for **all** students as future citizens, and the other designed for students with future studies in the sciences in mind.

Prospects

A much larger cohort of students at the end of the compulsory years will be positive about science. Such a cohort may well lead to more choosing science-based careers. Such a Science for Citizenship approach will lead to a general public with an improved understanding of science.

A curriculum for each stage will lead to a considerable simplification for primary teachers about what it means to teach science and consequently should produce in their students a more positive experience of science and technology.

Pre-requisites

Assessment modes for science that will convince teachers of science at all levels that the new goals their students are to achieve in S&T education is indeed a simplification.

ISSUE G: QUALITY OF LEARNING IN SCIENCE

Background

Improving the quality of learning in science and technology is the imperative behind the ***Perth Declaration's*** set of recommendations to governments. To achieve this imperative much else is needed, not least the quality of teaching in these areas, and attention is specifically directed to how this can be achieved in Section K. But this goal of quality learning in science and technology needs to be spelt out much more clearly, before the conditions to achieve it, including the role of teachers and their teaching, are considered. Teaching science and technology is not a goal in its own right. It a critically important means to the goal of quality learning among the students in science and technology classrooms.

It is not uncommon in English speaking countries to use the words, "Knowledge" and "Understanding" colloquially as synonymous or interchangeable. But in an educational document, these two words, and their equivalents in other languages, provide a real opportunity to distinguish between levels of intended learning.

In one recent national document outlining the details of a new school science curriculum, the science content, intended to be learnt, is listed under a heading, *Knowledge and Understanding.* Nowhere is there a clear statement about why these two words are used, or whether they are meant to be associated with differences in how these content topics are to be learnt. In such an official document, that is meant to give guidance to teachers, students and their parents, this is a lost opportunity to indicate that there are qualitatively different levels of learning in science.

There are many precedents for such differentiation in education more generally. Teachers will be familiar with *surface or shallow learning* in contrast to *deep learning*, *simple reasoning* vs. *complex reasoning, solving familiar problems* vs. *solving unfamiliar problems*, *simple tasks* vs. *rich tasks*, and *lower order skills* vs. *higher order skills.*

Older teachers may remember Benjamin Bloom's six tiered hierarchy for cognitive learning. It was common to associate his three lower levels with *simple knowing* and his three higher ones with *complex knowing or understanding*). Rodger Bybee (1997), Director of the Biological Sciences Curriculum Study Center in Colorado, provided two levels of learning that are indicative of fairly low level literacy, and two levels that relate to higher levels of literacy about the same topics.

Many countries are now participating in either or both the TIMSS and PISA projects, current large scale international studies of science learning. These two projects conveniently illustrate quite different intentions for learning science. The tests used in them provide examples of the levels of learning that these two intentions involve in practice. Barry McGaw, an international educator who has been involved in both projects, characterised TIMSS as testing what students **know** (or **remember**) from their school science, while PISA tests what students **can do** (or **understand**) with the science knowledge they have.

TIMSS tests students in Years 4 and 8 in the curriculum knowledge of science that is common across the participating countries for these years. PISA (Science) has a different purpose, namely, providing the educational systems in its participating countries with information about how well 15 year olds have been prepared for life in the 21st Century in the domain of Science. The PISA Framework documents make it quite clear that this project is concerned with a level of learning that involves the transfer of knowledge, that is, the application of what science is known to new situations of relevance in the today's world. (see OECD, 2000, 2003 and 2006).

A somewhat similar distinction between *having knowledge of science* and *being able to make use of it* has been prominent in discussions and studies of the Public Awareness of Science. Here simply knowing or being able to recall scientific information is referred to as *static or passive knowledge of science*. This is contrasted with *practical science knowledge in action,* that is, when citizens can actively apply their science knowledge to the situations in which they find themselves. David Layton contrasted these two levels of science with the metaphors of the *Cathedral of Science*, full of sacred books to be read, revered and recalled, and the *Quarry of Science*, a source to be raided for all sorts of uses in society.

Raising the quality of learning in science is not a contentious issue. There is agreement that learning levels should be high, but the levels of learning demanded in science courses at all levels have too often been indicated by the quantity of recalled knowledge rather than use to which this knowledge can be put. If important assessments of science learning concentrate on lower levels of learning they will be seen to be the goal of teachers teaching and students' learning. The meaning of *"higher"* levels of learning science needs to be made explicit to science teachers, who have themselves often reached their position through their love of science and their capacity to remember large amounts of its scientific information. The level of students' learning in science has been shown to be a consequence of the expectations that teachers demonstrate and encourage, through their use of challenging pedagogies in classrooms.

Recommendation

G.1 Policy makers should consider changing the assessment procedures, as critical curriculum factors, in ways that will encourage higher levels of learning as the intended outcomes of school science and technology.

Prospects
Students will gain a sense of personal empowerment in relation to science.

After leaving school they are more likely to engage with S&T issues in personal and societal life.

Pre-requisites
A revision of internal and external assessment instruments to emphasise higher levels of learning ***rather than the quantity of low level information.***

Basic science courses in universities, such as those undertaken by the majority of science teachers, should also be change their demands on students so that they, in due course as teachers, will become ***familiar with higher levels of learning science.***

ISSUE H: THE USE OF ICT IN SCIENCE AND TECHNOLOGY EDUCATION

Background

Perhaps the single most influential applications of science in the last 25 years have been those that have made placed hitherto unthought of possibilities for communication, first into the hands of organisations and now into the hands of individual persons themselves. Across the world we all now live in a Global Communications society, in which knowledge and information are the currency. The possibilities for exchange and interaction of knowledge are regularly being redefined and extended, as new scientific principles and materials are being, ever more rapidly, put into application. The advance of these practices through science and technology has been so rapid that schooling itself, and science and technology education in particular, has been largely left behind in deciding how these new possibilities will be built into its practices. Meantime, the lives of young people outside of school are now irreversibly different from even what the lives most of their teachers enjoyed at the same age.

What then are the issues that science and technology education should be considering as it strives to catch up with the digital technologies that are so widely in use in society outside of schools? How might the practices of science and technology education be improved by these new resources?

The lag between use of ICT in schooling and its practice outside is illustrated by the OECD's PISA Science project. In 1998, when the planning for its extended six-year cycle of tests began, the Science Expert Group expressed the hope that by the third testing in 2006 students, at least in a number of countries, would be taking the test in front of a computer. This hope was quickly extinguished for the main testings, but the chance did arise to develop a computer-based instrument as an optional test in 2006 when Science was the major domain of PISA. Some interesting units were developed that met the strict criterion that they were to involve aspects of science and technology that could not be presented in a paper and pencil test. Hence, modelling and dynamic aspects of scientific phenomena were prominent for the first time in a potentially large scale test for scientific literacy. The units were designed for use with laptop computers to avoid known problems associated with trying to use them via the internet or school-based servers. In the event, only four among the 30 richest countries felt able to participate and ensure their participating students would all have access to this laptop delivery!

The use of multi-media software to simulate processes, present three dimensional structures, and carry out virtual experiments, are among the most innovative and exciting possibilities for science and technology education, since traditional descriptions of these visa text-books or oral presentations are confusingly simplified or unduly complicated. Thanks to the new communications technologies they become as available to remote schools and classrooms as to ones near to the source. As yet, the provision and use of these types of application of ICT are still in their infancy in most educational systems. There are substantial capital investments to be made, but the potential that these technologies have to offset the educational disadvantages that plague all systems are substantial. The expenses associated with the provision of quality laboratories, and equipment has made science and technology education a prime source of uneven educational opportunity, but the sensible and imaginative use of ICT can be a means of by-passing this.

More common at present is the use of ICT tools for data capturing and processing, publishing and presenting reports, computer projecting of charts, graphs and diagrams, and computer control of instruments like microscopes, telescopes, and microprobes. It is important that these usages are explicitly chosen to enhance both the practical and theoretical aspects of science and technology teaching and learning. In *Report 6* for the *FUTURELAB Series*, Jonathon Osborne and Sarah Hennessy (2006) have provided a comprehensive description of these digital innovations and the potential; they have to advance science and technology curricula in the directions the **Perth Declaration** is promoting.

Some of these pedagogical advantages are:

- release from laborious manual processes so that there is more time for discussing the meaning of observations and results,
- increasing currency of the science and technology by providing access to their worlds of practice,
- providing immediate visual feedback to thought experiments and to output from instrumentation,
- directing attention to the larger aspects that is often distracted by the details,
- illustrating the salience of abstract concepts,
- encouraging self-regulated and collaborative learning,
- increasing personal engagement, and
- enhancing interest in science and technology and in their learning.

The sharing, across national boundaries, of school-generated data about science and technology issues has been a communications feature of ICT in a number of environmental projects. Their associated value in breaking down cultural differences cannot be overestimated.

David Layton, in discussing the public's understanding of science, used the metaphor of science being 'a quarry' to be raided when you need its contents. The Internet has made this possible in a way that the largest textbook, or the better informed science teachers could never achieve. Once again, this is already transcending to a large extent the division of resources between the rich and the poor, and teachers of science and technology can take advantage of this to gain access for their students to all manner of scientific information. How to prevent this being an undigested flood of information is, however, an issue where the teacher needs to have their goals for learning in science and technology education firmly in mind. Once again the purposes for science and technology education discussed in **Section A** above must be the basis for deciding how these powerful ICT tools will be used.

Recommendation

H.1 Policy makers should consider the cost, provision and maintenance of ICT across the school system in terms of the educational benefit and equity it will bring to schooling in general, and *to science and technology education in particular.*

In revising the curriculum for science and technology, an explicit emphasis will be needed on those aspects of these areas that these ICT tools now make possible.

Prospects

The measured integration of ICT into science and technology education will enable this education to be more in touch with S&T in practice.

Real changes in teachers' pedagogy become possible with positive effects for a wider set of learners.

The interactive possibilities of ICT will support students' reasoning and critical analytical skills.

Pre-requisites

The intentions for ICT in relation to the revisions of the S&T curriculum must be made clear to teachers as they are challenged by professional development programmes to add these tools to their pedagogical repertoires.

Provision of the ICT services and tools could begin in less advantaged schools to trial these new curricular emphases and to demonstrate the equity prospects that ICT usage can have.

ISSUE I: DEVELOPMENT OF RELEVANT AND EFFECTIVE ASSESSMENT IN SCIENCE EDUCATION

Background

Assessment of learning is integral to the process of learning. How it occurs is a very powerful factor in the effectiveness of the whole process of teaching and learning. In the process of learning itself, it is usually referred to as *formative assessment*. Its purposes are to help students become aware of what they are supposed to be acquiring in the science classroom, and to give them indication of how well they are acquiring. At the conclusion of a longish period of teaching and learning it is common for an assessment to occur which provides a summation of all the learning during this period. This is a *summative assessment*. Sometimes the source of such a summative assessment comes from the wider system, beyond the teacher or the school, and it can be used to credit the student with respective to future possibilities for further study or for vocational purposes. Although formative assessment should always be for the purpose of improving a student's learning, it can have the success or failure effects that summative assessments so often confirm. To avoid such effects teachers need to work with students in ways that self-assessment becomes part of the student's own learning repertoire.

There are a very rich variety of modes for formative assessment but many of these are not familiar to teachers. Workshops to increase their skill and confidence in sharing these assessment tools need to be a regular part of teachers' professional development.

In too many countries (although some continue to resist) the mode of assessment of science learning in schooling is by simple multiple choice testing for which banks of items are externally available. These banks, once developed, have a beguiling attraction because of their relatively cheap cost of administration, particularly with machine marking when large numbers are involved. Simple multiple choice test items are most suited to checking the extent to which students can recall conceptual and definitional science content and low levels of application of this knowledge. They are, however, very limited in extent to which they can monitor other important aspects of science learning, that are intended in the science curriculum. For example, they cannot give measure of how confidently and accurately carry out practical investigations in science. They cannot easily assess students' development of science concepts. They cannot indicate how well students can suggest explanations for scientific phenomena or argue how the case for a scientific conclusion should be reached. They have very limited application to measuring the progression of a student's interest in science. Teachers, on the other hand, are well placed to make such assessments. Accordingly, it is most important that teachers be assisted to accept that assessment in all its rich variety is integral to their role as teacher.

This use of multiple choice test items has been exacerbated by the growing pressure for state-wide standards for science learning across whole cohorts of students. This use, in some cases, seems to be more about a public accountability of teachers and schools, than it is about providing indicators to improve the teaching and learning itself. The use of these test items, as the dominant mode of assessment in the large cross-national comparative studies of science learning, such as TIMSS and PISA, has appeared to give them credibility. In 2006, PISA (Science) innovatively used complex multiple choice items to open the way in paper and pencil assessment to a wider range of science procedural learnings. PISA (Science) also makes more use of free response items, that enable questions with more than one answer, and these allow some exploration of the reasoning behind an answer. This test has also made history by including affective items in the main achievement test (PISA Science Framework, OECD, 2006).

School science in most countries has traditionally held that hands-on practical investigations should be an integral part of the subject. The assessment of students' learning in relation to the practical skills and cognitive processes involved in such investigations is fraught with problems, that are made more complex when open-ended investigations (desirable for many reasons) replace "recipe-type" practical work. Whatever the level of practical science learning is involved, it is only the teacher's regular observation of their students' performance that can provide an authentic assessment. There is a strong consensus that with respect to the learning of laboratory aspects of science, there are no surrogates to replace the students' teachers!

Whatever a curriculum's purposes (see section A) for science education, it is crucial that these be reinforced by both the formative and summative modes that are used in practice for assessment. This match between aims and intentions and the means of checking on their achievement is called *authentic assessment.* For even a modest set of aims or purposes, a number of different modes of assessment will be needed for authenticity.

Recommendation

I.1 Policy makers should consider how the intentions of the science curriculum for students' learning can be more authentically assessed, both within schools and externally, by the use of a wider variety of assessment tools.

Prospects

More students would find aspects of science learning in which they were successful. The efforts of science teachers would be more reflected in their students' learning. Deeper levels of learning the more important ideas in science will be encouraged.

Pre-requisites

Teachers, curriculum developers, and assessment boards will need to become familiar with, and confident in the strengths and limitations of the variety of assessment tools that is available for science learning. probably the most effective professional development that science teachers can have.

The increased costs associated with authentic assessment will need to be considered against the benefits for individual students and for the society that more authentic assessment in science education would bring.

The moderation, by other teachers of a school's internal assessments of science would provide probably the most effective professional development that science teachers can have.

ISSUE J: SCIENCE EDUCATION IN THE PRIMARY OR ELEMENTARY YEARS

Background

The **Perth Declaration** calls for revisions of the curriculum for school science and technology that will increase interest in, and recognition of the roles of science and technology in society. This call relates to the teaching at all levels of schooling, including the primary or elementary years. Indeed, the Perth Forum stressed the importance of science and technology having a strong presence in the educational experience of these young learners. The fact that in some countries many students still only attend school in these years makes better science and technology education an urgent goal to achieve. It is, however, only realistic to recognise that most countries have had, and continue to have, factors and conditions at these primary levels that make the teaching of science and technology particularly difficult. Accordingly, these years represent a level of schooling to which policy makers should give special attention in relation to their revision of the curriculum for science and technology education. Some of the difficulties and major issues are now outlined.

The production of specific resources for the teaching of science in the primary (elementary) school years has been part of the overall science education scene since the late 1960s. They swung between encouraging young children to have first hand open inquiry encounters with natural phenomena and quite formal introductions to the so-called process skills of science. Many primary teachers, with their limited backgrounds in science, found the openness of the former materials too threatening, and the latter, divorced as they were from science content, were easier to teach especially in social science contexts for which they also had meaning. In the mid-1980s, materials were available for teaching science through practical examples of technology and these were welcomed by some teachers because they engaged the children with hands-on activities that made sense to them compared with the more abstract contexts of science.

Until the 1990s, however, science was usually part of the formal primary curriculum, but in practice it was very spasmodic, depending on the enthusiasm of individual schools and teachers. The experience with primary science education in the twenty five years since the 1960s provides a long record of high hopes, but unsuccessful attempts, to give science a more persistent and assured positive presence in the education of these young learners. Every variety of support for primary science has been tried in one country or another, and often more than once - *new types of quality resource materials, packaged kits of equipment, professional development programmes, science specialist teachers, a stronger emphasis in pre-service education, recognition in international testing, etc.* This record is a testimony to the special difficulties facing science and technology education in the primary years, and should not be overlooked in the framing of the new approaches that are called for in the **Perth Declaration**.

The key difficulty facing primary science education in most countries is the fact that the persons who become primary teachers, as a whole, lack the confidence in, and knowledge of science, to teach it as intended. Few will have studied the physical sciences in the later years of schooling or at university, and a number, no science or technology at all. Indeed, they have chosen primary teaching as a career very often because they are interested in children (rather than subjects as science is seen to be) and they were not interested in science during their own schooling. Primary teachers are trained as generalist teachers of children. Their secondary colleagues are trained in one or two subject specialties, and it is in those specialist areas that they see themselves as equipped to teach. Within their school's staffing availability they will usually be found teaching in those areas.

The pressure in the pre-service education of primary teachers to equip them for teaching number and language literacy, together with history, geography, art, music, health, etc. leaves little time for the very substantial re-education in science and technology that is needed. Even when strenuous efforts at professional remediation for science and technology were tried in the long past, and again more recently since the 1990s, they have only marginally improved this situation.

Another influential condition is the fact that primary schools are not equipped for science and technology teaching in the way that secondary schools usually are. There are no special rooms with space for setting up equipment and with cupboards to store it when not in use. Primary schools do not have laboratory assistants as is now regular in many countries' secondary schools. Finally, there is not widespread support, from parents or employers, for science and technology to be priorities in the primary years. Perhaps this is due to the fact that these adults did not themselves experience science in their primary schooling, and do not identify it as a key to a successful or full life. After all, the evidence for scientific literacy among these adult groups is not high, and its level has not had a great bearing on their own success in life.

In the 1990s the revisions of national curricula in many countries heightened the status of science and technology in the primary years. Policy makers declared them to be important. In some countries science was even declared a "core" subject. Detailed lists of content for teaching and learning were drawn up that stretched from Year 1 to Year 10 or 12. Primary schools were required to ensure that their years of these '*long ladders'* of science content were taught on a regular basis, and in some countries, high stakes examinations to monitor this were instituted. Despite the very obvious differences between the human and physical resources for teaching science, that exist in primary and secondary schooling, the nature of the knowledge to be learnt, and the content that is thereby emphasised, was the same in the two levels. Indeed, much of this content was disciplinary knowledge that hitherto had been part of the more senior secondary science subjects.

At the very same time as this teaching and learning of conceptual science content was expected, primary schools and their teachers faced heightened pressure to give even more attention to the tasks of raising the levels of their students' literacy and numeracy. These pressures, together with a general lack of strong parental and public support for science in these years, has meant that the time allocation for science and technology education in many schools falls well short of the 10% recommended in the **Perth Declaration**. With such minimal time and so much content to cover it is not surprising that transmissive coverage of the content takes precedence over the active investigations that these curricula also say is intended. Quite recently, evidence is appearing that this type of science in the primary years may be contributing to the lack of interest in science and in science as a career that are now so widespread among secondary schools students across the more developed countries.

In general, primary teachers are more pedagogically skilful than secondary subject teachers, and they practise these skills regularly. More flexible curricula for science and technology in the primary years are needed that will encourage these teachers to the use the full range of these skills, and that do not present science and technology as very separate and alienating areas of study.

For example, those primary teachers who like to teach in an integrated fashion should be encouraged to include the science and technology aspects of some of their thematic studies. They could also choose S&T contexts in the lives of their students as the themes for their integrated teaching and learning. Other teachers may find it convenient to use science stories and topics in their literacy teaching. Many simple examples of technology lend themselves to active hand-on learning and in the process young students can gain useful pre-conceptual experience of the related science. Because science investigations usually take more than one lesson to complete, it could be useful to sometimes replace weekly lessons by a "science and technology event" lasting a whole school day. In this way, S&T can take on the exciting character that excursions have, and schools can plan for these spectacular events as a whole class investigation of a meaningful problem, drawing on help from parents and local scientists to assist the teachers.

The wonder and fascination that so many natural phenomena and living species inspire, are great starting points to develop the curiosity and creativity that these young learners bring to school. A sense of excitement about nature might be the very best learning outcome for teachers to achieve in science and technology education in the first years of schooling.

Recommendation

J.1 Policy makers should consider a quite different curriculum for science and technology in the primary years, that engages the considerable pedagogical skills of these teachers, provides their young learners with a series of positive and creative encounters with natural and human-made phenomena, and builds their interest in these two areas of learning.

Prospects

Primary teachers will feel more able in their teaching of science and technology. Students will acquire a rich base of experiences for the more conceptual and values aspects of S&T\that is better dealt with in the secondary years.

Student affect would be improved, because of their active engagement with motivating phenomena and the immediacy of their experiences.

Pre-requisites

Teachers and schools would need to be convinced that they had a real part to play in developing theirstrengths into quality learning experiences for S&T education.

Teachers in pre-service and post-service education would need help with what are fruitful natural phenomena to use as the S&T contexts, and with the many ways they can actively engage their students in them for positive learning experiences.

ISSUE K: PROFESSIONAL DEVELOPMENT OF SCIENCE TEACHERS

Background

The **Perth Declaration** makes a strong recommendation that governments should 'resource and promote continuous, effective professional development for science and technology teachers so that they can meet changing student needs and societal aspirations'. Behind this recommendation are three recognitions. The first is the truism that the fundamental factor in the improvement of students' learning in science and technology is the quality (knowledge, skills and enthusiasm) of their teachers. The second is that science and its everyday applications as technology, are dynamic phenomena for which no initial training in science and its teaching can be adequate for very long. The third is that 'students needs and societal aspirations' are now very different from what they were assumed to be when the content and structure of so many of the curricula for school science were established . This third recognition is also why the **Perth Declaration** is calling urgently for 'revisions of the curriculum for school science and technology'.

It is very common for science teachers (secondary) and teachers of science (primary) to begin their studies in a Teachers College or a University straight from school, and then, on completion return to schools as teachers. The secondary teachers are likely to have taken one or more sciences in the final years of school, and to have continued with these at the undergraduate level in combination with studies in education concurrently or subsequently. At this undergraduate level their science learning will be almost entirely bounded by established textbook knowledge. Graduates from these programmes know a great deal of science as information, but comparatively very little about its generation as such within the processes that make up the nature of science. That is, teachers with this type of science background are strong in the *Knowledge* ***of*** *Science,* but weak in *Knowledge about Science*. Hence, they are poorly equipped to undertake the shift in the curriculum to the balance between these types of knowledge that is called for in Section E above. In only a few countries do secondary teachers study science at a post graduate level. Yet it is only at this level that they have the opportunity to become aware of research at a frontier edge of science, and hence of gaining some personal experience of the procedures whereby scientific investigations of pure and applied science problems proceed.

Primary teachers may have only taken science in the compulsory school years, and perhaps one science subject, usually biology, in the later years. As noted in the previous section, the tertiary studies in science and science education for future primary teachers are generally very limited, and it is a rarity for them to have substantial studies in the sciences themselves.

In the light of the initial education in science and education of these two sets of teachers, it is quite unrealistic to think that pre-service education, alone, can equip either group of teachers for teaching science and technology with the quality and dynamic character that are called for in the rhetoric of so many reports and curriculum documents. In order to interest students of all ages school science must reflect some of the richness and excitement of science itself. This involves teachers having an awareness and access to some of the issues, problems and questions, that scientists are asking as they explore the natural world, and as they try to tackle the issues that lie at the interfaces between science and technology and society. Hence, professional development in both science and technology and in new ways to teach them are essential needs for science teachers, both primary and secondary. The issue is not whether such professional development (p.d.) is necessary. Rather, it is how it should occur?

Many modes for professional development exist, but by far the commonest one is to bring science teachers together for a few hours after school, for a rare pupil-free day, or for a conference in a school vacation. On these occasions they are usually offered a range of workshops on many aspects of science teaching, as well as science lectures by leading-edge scientists, etc. These events are like a smorgasbord type feast. The teachers dip into this and that, but always aware that in the next hour they will be doing something different. Too often, the teachers attending are the keen ones and not the ones most in need.

This commonest mode of professional development is also the mode that research has shown to be least effective. Alas, in the face of no obvious alternative and their dependence on voluntary leadership, Associations of Science Education (Science Teachers Associations) have been major contributors to this inefficiency in their annual conferences and other meetings.

To be effective a professional development programme has to be focussed on one aspect, whether it is upgrading in a science and technology topic or a particular teaching and learning strategy. It also needs to extend over time so that the new ideas put to the teachers can be tried out in school, and their success or failure can be reviewed in a subsequent session and refined. With such a sequence the problems that inevitably turn up when new ideas are tried out in many different school contexts can be discussed and hopefully dealt with. This type of professional development can only take place, when there is recognition in the educational system, that all science and technology teachers need this type of personal re-equipment, periodically throughout their career, in order to provide up-to-date and quality teaching. Of course, such ongoing professional development costs a lot of money, especially when the teachers need to be out of their schools for some days. However, many educational systems are at present putting considerable time and financial resource into relatively ineffective modes of professional development; and those resources would be better spent in starting to establish more effective modes. Many other employers of professionals have now accepted that it is their interests to ensure that their staff is personally so re-equipped.

There are many examples of how serious professional development can occur, but these are often restricted in scope and hence in the numbers of teachers they develop. Some have been bilateral in origin, such as the *Strengthening of Mathematics and Science at Secondary Education (SMASSE*, Kenya/Japan), but that programme has now extended to other African countries through the *Centre for Mathematics, Science and Technology Education in Africa* in Nairobi. This Centre has residential, laboratory and classroom facilities serving 23 countries, structural recognition for its important work in developing teachers in these fields. by the *New Partnerships for Africa's Development (NEPAD)* programme. Others are home grown, like *Learning by Doing* at the Southeast University in Nanjing, China, the *Ensenanza de la Ciencia Basado en la Indigacion*, promoted by the Chilean Academy of science and that country's Ministry of Education, and the *Small Science* one from the Homi Babha Centre for Science Education in India. Projects that have been successful need to be taken up by state authorities and extended systematically to all teachers. A structural model in a developed country that is of interest is the recent *National Centre for Science Learning* in England. It has a residential facility at York University and a number of non-residential satellite centres in other places around that country.

As these types of professional training are recognised and are being established, national associations for science teachers should be asked to play a major role in defining and implementing teaching standards for science and technology education. This has already happening in some countries.

Recommendation

K.1 Policy makers should consider the policy implications (financially and structurally) and the benefits in establishing the provision of ongoing, focussed professional development in science and technology and their teaching, as an essential aspect in the careers of all science teachers.

Prospects

The quality of the teaching and learning of science would begin to improve rapidly.The morale of science teachers would improve, and fewer would be lost from the classroom to administrative positions or to employment outside education.

The needs of under-qualified teachers of science in the system would also be effectively met. Students would experience a dynamism about science and technology that is, at present, often not present Complacent teachers will be confronted with strong challenges.

Pre-requisites

Recognition that quality teaching cannot rely on a basic initial training and that, like other professions, educational systems must provide the means for teacher up-grading. A realistic appraisal of the inadequacies of the present provisions for p.d. as well as their failure to include all teachers. The current effort and resources for p.d should be better spent making a start on what are demonstrably more effective modes. Science Teacher Associations as representative bodies for science and technology teachers should be partners in building the political case for funding in national budgets and educational systems for professional development that will raise the quality of science teachers, and hence, expand the number of students receiving quality S&T education.

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The Perth Declaration on Science and Technology Education

We, the participants at the 2007 World Conference on Science and Technology Education, held in Perth, Western Australia, 9-12 July 2007, and comprising more than 1000 science and technology educators from 50 nations worldwide; believing in the importance of science and technology for **sustainable, responsible, global** development, and in the need to bridge the gap between science and technology and the public.

Express concern at the lack of recognition of science education as a vehicle for meeting national educational goals, and social and economic needs;

Observe a widespread lack of student interest in current school science and technology education and of its relevance to them;

Note the shortage in many countries of specialist teachers of science and technology;

And consider that the rapid changes taking place in science and technology and their applications must be reflected in the planning, teaching and learning of science and technology.

Resolved to recommend to Governments:

- To promote critical awareness of the contribution of science and technology to personal, social, economic and environmental wellbeing through building partnerships with national stakeholders and the media;

- To initiate revisions of the curriculum for school science and technology that will increase student interest in and recognition of the roles of science and technology in society;

- To promote from the primary years onwards the career opportunities that stem from the study of science and technology;

- To recruit graduates into science and technology teaching and to value, support and retain them with appropriate rewards;

- To resource and promote continuous, effective professional development for science and technology teachers in order to meet changing student needs and societal aspirations;

- To recognize and support the significant role of teacher associations in building a quality professional learning community for science and technology;

- To resource the development of relevant and effective assessment processes so that learners achieve essential life skills, meet academic and vocational standards and personal aspirations;

- To engage in greater international cooperation to ensure the provision of well-trained science and technology teachers to meet current and future challenges;

- To call on UNESCO to integrate its science and technology education endeavour as fundamental to achieving educational, environmental, cultural, social and sustainable development goals.

We, the participants, are committed to ensuring that students are scientifically and technologically literate and able to contribute to sustainable, responsible, global development in their respective nations.

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