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FOREWORD

Our world is profoundly shaped by science and technology. Preserving the environment, reducing poverty and improving health: each of these challenges and many more require scientists capable of developing effective and feasible responses – and citizens who can engage in active debate on them.

In order to achieve this, the 1999 Budapest Declaration underlined the importance of science education for all. Indeed, science and mathematics education (SME) that is relevant and of quality can develop critical and creative thinking, help learners to understand and participate in public policy discussions, encourage behavioural changes that can put the world on a more sustainable path and stimulate socio-economic development. SME can therefore make a critical contribution to the achievement of the Millennium Development Goals adopted by the world's leaders in 2000.

Recognizing this, UNESCO created the International Group of Experts on Science and Mathematics Education Policies, whose first meeting on SME in basic education was held from 30 March to 1 April 2009. The conclusions from this meeting, which form the basis for this publication, show remarkable consensus on the challenges faced by SME today and how these can be addressed. All the experts agreed that the last decade has witnessed the development of a substantial body of knowledge on SME and the production of valuable tools and resources, many of which are now widely accessible thanks to technological advances. These are a firm basis to build on and open new perspectives for evidence-based policy for SME.

This publication therefore defines the challenges faced in the implementation of quality SME in basic schooling and, using case studies, sets out ways of improving its delivery. It will be of use not only to decision-makers wanting to mainstream quality SME education into their systems, but also to stakeholders who wish to participate in the change process.

UNESCO hopes that this publication will help mobilize the energy and enthusiasm of children, teachers and parents for improving SME. Indeed, working together on developing quality basic SME in a sustained and coordinated way is the ***sine qua non*** for ensuring a fairer and more sustainable future for all.

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1. Introduction and Rationale

Science Education and Mathematics Education share several commonalities in regards to the values, as well as several challenges. However, while the position of mathematics is well established with its own logic and approaches, the case of science in basic education is rather different. At the international level, recognized in the Budapest Declaration, and often by national governments, the case for science in basic education is clear. However, its position in classroom practice is less well established, even in well-resourced systems, for example Australia or the United States. This means that approaches to science teaching and learning are less widespread and so some of the challenges for developing science education are different from those facing mathematics. What follows is a review of reasons for including science as an essential requirement of basic education and the challenges that this presents to schools. Firstly, there will be a review of the role of science education and how it can contribute to improving equity and equality. Secondly, we draw on a view of schooling as an essential introduction to culture and to powerful ways of thinking that humankind has developed (Savater, 2004). Science is seen as an essential part of culture and a powerful way of thinking. The third reason is that science education is necessary for the world of work and the economy. Finally, the challenge of making connections between globalization and science education will be explored.

What follows is a review of reasons for including science as an essential requirement of basic education and the challenges that this presents to schools.

1.1 Science Education, Equity and Equality

Scientific development in recent decades has, and will continue to have, a significant influence on topics that have great importance for humanity, quality of life, the sustainable development of the planet, and peaceful coexistence amongst peoples. From the immediate basic essentials of life such as access to water, food and shelter, to important issues that affect us all (management of agricultural production, water resources, health, energy resources, biodiversity, conservation, the environment, transport, communication), all have a strong science component to which everybody should have access to take part in local, regional, national and transnational decisions in a meaningful way. We also live in a world where poverty and riches live side by side and where

The data clearly show that the greater benefits that science brings are unequally distributed.

the gap between them is increasing. The Declaration of Budapest argues that what distinguishes poor people or countries from rich ones is that not only do they have fewer possessions but also that the large majority remain excluded from the creation and the benefits of scientific knowledge. The data clearly show that the greater benefits that science brings are unequally distributed. This translates into inequality and injustice between countries and between social groups. It reinforces the continuing exclusion of groups from the knowledge of science and the benefits of its use, through belonging to particular ethnic, gender, social or geographic groups. Science must not only respond to the needs of society in order to improve the quality of life of the majority population which lives in poverty; it should also be used by all citizens, men and women. To be usable, scientific advances have to be known and owned. The philosopher Fernando Savater, writing on this issue, is clear on the importance of science for all and the impact of being excluded from such knowledge.

> One of the most perverse ingredients of poverty, allow me to insist on this, is ignorance. Wherever there is ignorance, that is where the basic principles of science remain unknown, where people grow without the ability to read and write, where they lack the appropriate vocabulary to express their longings and desires, where they are deprived of the ability to learn for themselves what they need to resolve their problems… there reigns poverty and, there, there is no freedom,
> (Savater 2004, p.174, author's translation.)

In the 21st century, science must become a good shared by all, for the benefit of all people. The view of science that this document proposes will make a significant contribution to combating the forms of ignorance identified by Savater. It is a view of science learning that will deal with scientific principles through an approach where children are taught, and learn, to write and talk about science, to argue for their views of the world and how they can draw on this knowledge to help in decision-making. This is no small challenge yet we are inspired by the ideas of Amartya Sen (2001) on the link between poverty and freedom, education and liberty. People need access to the necessities of life in a world where there is more than enough for everybody. They also need access to ways in which they can expand the freedoms they experience, and develop the capacities needed to take advantage of such opportunities, and so become more human. We propose an approach that shows how school science can make a significant contribution to this enterprise by outlining a view of school science that deals with the challenge of ways of **learning science** and ways of **learning through science**. This approach is designed to contribute to the challenge of the ever-growing realization of the need for scientific understanding to support decision-making, and to be able to take an active part in decisions that affect all our communities. Every citizen needs to be able to take decisions that affect individuals, communities, regions, our countries and the world, decisions that need a science education based on an understanding of ethics and of interdependency. Thus, science learning has to be seen as necessary for the full realization of a human being. When the majority population is scientifically illiterate, it not only aggravates inequity but also presupposes the exclusion of this majority from true participation in and influence on their environment. Therefore, we are obliged, not simply from an educational perspective, but also from that of ethics and social commitment, to increase efforts to ensure that all have access to an appropriate scientific and technological culture. While some argue for the need to concentrate resources on high-achieving students in science, international studies such as TIMSS (2008) and PISA show that where systems are more equal, country outcomes in international comparisons are higher.

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This right to universal access to quality science education has been recognised for some time by UNESCO, with recent refinements of the arguments in its favour (Macedo 2006, 2008). The challenges to achieve this quality basic science education are many. First, access alone presents many facets. Whilst science has come to have an important place in basic education in many parts of the world, sometimes it is almost non-existent in primary education. In less favoured countries, primary education is often the only education for the majority of students. It is essential, therefore, to establish the place of science for all in elementary or primary education and thus meet the challenge of quality science education for all. Without access for all and the ability to make use of the opportunities that school offers there can be no quality science education. What is proposed below is a new way of doing school science to meet the challenges that we will identify. We hope such a school science will go some way to combat the poverty of mind and body that is a daily experience for so many of our fellow human beings. In our interconnected world, their restricted humanity affects us, as our continued living with this situation inhibits our ability to become ever more human (Singer 2009). We should all fight to ensure that we can all become more human, and school science has a key role to play.

1.2 Schooling, Science and Culture

All societies in the world have ways to educate their young members to ensure that they become full participants in society, are able to contribute and develop it and so become more human (Savater 2004). What is debated is what to include in such an education. Education introduces us to valued aspects of the culture of society as well as aspects of culture that are important for the members of that society. In schools and schooling, that has always included a range of disciplines or subjects that have value for the society and in turn offer value to members of that society. The particular aspects that science offers for education, as well as its more general contributions to education, has been explicit for many years and it is now time to make these a reality. In today's world, science has a key part to play. Science is the triumph of the work of women and men from around the world, working with care, rationality, playfulness and creativity. It has its own structures, ways of thinking and working. It has its own beauty, awe and wonder and offers a powerful way of looking at the world (Chalmers 1999). Such aspects - awe, beauty and creativity - should form part of the education of children today and are more likely through the practical approaches discussed below. This approach offers a challenge for the people involved in education, especially teachers. Some of the ways that this challenge might be met are shown in Section 5: Teachers and Science.

Science is the triumph of the work of women and men from around the world, working with care, rationality, playfulness and creativity.

Another benefit of a quality science education for all is its contribution to developing ways of thinking. Many scientific ideas are counter-intuitive as we know from many investigations. Pozo (2008) has shown in a variety of contexts that thinking scientifically helps develop new ways of thinking; it widens and deepens our capacities to think. Thinking about and with scientific ideas means we have to think in new ways that offer powerful possibilities for the future, and are not often spontaneously available without teaching. This idea is developed further in Section 2.3 Science for All.

Science education would also open up the possibility for more and more citizens to experience the joys and delights of the human enterprise that we call Science and to feel part of it. This is a pressing argument in favour of an urgent reformulation of science teaching and learning.

1.3 Science Education and the World of Work

All schools and schooling systems accept that part of their role is to prepare children for the world of work, sometimes implicitly and, more and more, explicitly. To achieve this aim, school systems and their stakeholders will see that affective and motivational aspects of science learning are important not only in the classroom, but also in the wider societies.

In two lectures given at the University of Montreal in 2008, the former Assistant Director-General for Education of UNESCO, John Daniel, presented a convincing argument for education as the way to development for all and in particular for the development of less developed countries. President Obama in his address to the national Academy of Sciences in April 2009 (Obama 2009) took the same approach. His administration is attached to the idea that the United States, which has one of the most influential economies of the world, must increase its scientific activity and, above all, improve the quality of science education at all levels as a way for the country to overcome the financial crisis and its effects. Obama acknowledges that the connection between, national and personal development on the one hand, and increasing the quantity and quality of science education on the other hand, is not simple or direct. However, he argues that action is necessary. This example suggests that every society must pay particular attention to the scientific and technological education of its future citizens.

Work on student attitudes to science suggests that this increase cannot be achieved by more of the same school science. Decreasing interest in school science shown by students across the world is an important challenge (Royal Society 2008a). There are well-documented studies of declining interest in science and science careers in both primary (Jarvis and Pell 2002) and secondary schools (Royal Society 2008b; Sturman and Rudduck 2009, TIMSS, PISA). In his 2009 address, President Obama identifies this as a global issue. It is vital that we increase the interest of students in science. In addition, certain groups are under-represented in science careers: girls, minorities, people from lower socio-economic groups. We need to take steps to explore reasons for such inequality and move to remove barriers to participation.

While this trend is clear and may at times seem overwhelming in its demands, similar studies also show that students in basic education (Jarvis y Pell 2002, Talentito-Neto, 2008), teachers in initial education and those working in the classroom (Osborne y Collins 2000, NFER 2008), all overwhelmingly agree that science and technology are interesting and important for them and that they should be included in basic education. Teachers (Duckworth 1995) and children (Jarvis y Pell 2002, Clarke et al. 2008) enjoy working with science ideas, especially when they have the opportunity to investigate their own ideas and compare them with the ideas of standard science. Challenges facing society, such as energy, genetics, and climate change, are of great interest for a variety of people. The implication from this is clear and goes some way to providing an answer to the challenge of declining student interest in science. Students reject a school science that is disconnected from their own lives, a depersonalized science, where there is no space for themselves and their ideas. The international review comparing 15 year-old students' views of science with other subjects, carried out by the International Council of Associations for Science Education (ICASE) and the Australian Science teacher Association (ASTA) with the support of UNESCO, reached a clear conclusion on why students might lose interest.

> Students reject a school science that is disconnected from their own lives, a depersonalized science, where there is no space for themselves and their ideas.

- **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 of 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 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**? (Fensham 2008 pp21-21.)

In addition, many non-science careers are more financially rewarding.

Their Review also shows that where a more transmissive approach is used with younger children, they choose to leave science at a younger age. However, rather than assume a single cause, it seems to be that a combination of, or interaction between, these causes for different students and places that is important (Porter and Parvin 2009). So all these features need to be attended to. The companion meanings that students attribute to science are undesirable in terms of encouraging further study of, or life-long interest in, science. There is another, important reason why action is needed. The image of science embodied in students' perceptions identified by Fensham (2009) is far removed from the reality of science as practiced by scientists. Rather than learning or being taught the nature of science or knowledge about scientists, students are making attributions that challenge basic science education.

> Such a humanistic school science empowers and motivates people to change their lives and the communities they live in.

One answer seems to speak loudly from such surveys; school science has to emphasize working with ideas rather than transmitting information, through scientific investigations of students' own ideas, on science topics related to ongoing, current scientific issues of the day (Márquez Bargalló y Prat 2010). As we will see in Section 3 Developing the Teaching of Science, these outcomes from consulting learners coincide with recommendations coming from research on teaching and learning science. Thus, we can see a way to deal with the challenge of declining interest in science and a way to support a positive view of the social and personal relevance of science. Such a humanistic school science (Aikenhead 2005), building on earlier work of writers such as Comas Camps (1925), and Reid and Hodson (1987) empowers and motivates people to change their lives and the communities they live in. Such a humanistic science for all will also be truer to the nature of science in the modern world. Students often draw scientists as older, white men, working in isolation on dangerous activities in laboratories (Fensham 2008). This is far from the way that most scientists work, namely, in teams, in and out of the laboratory in the wider world, in cooperative competition to develop scientific thinking. This more realistic view of science ought to be one of the desired, explicit outcomes of school science, through teaching and learning, and as a companion meaning from the way that students learn science. Thus, students will develop a more realistic understanding about the nature of science and how it operates. They will be able to see science as part of the rich heritage that previous generations have bequeathed to us, a living, growing corpus of ideas, that are subject to change as new observations and ways to interpret them appear. Such a science is not a dogmatic body of unchanging truth but a science that offers us knowledge, understanding and methods of working that offer powerful ways to look at the world. It connects with other curriculum subjects and with the lives of the students in and out of school and their communities.

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Such a view of science should chime with the interests of the students and encourage them to continue studies in science. They will then have a wider range of options available when they enter the world of work. In this way, quality basic science education contributes to reducing inequalities by providing wider possibilities for future citizens.

1.4 Science and Globalization

All over the world, we are living through a transformation of the global economy. At the start of the twentieth century, the world's economies were based largely on agricultural production and natural resources, then on industrial production and transformation, then on services. Towards the end of that century, and certainly from the 1990s, the current, and probable future scenario, is the knowledge economy.

The expression the 'knowledge economy' or, more accurately, the economy built on knowledge (OECD 1996) evokes the new paradigm which characterizes the evolution of industrial nations. Economic structures, which previously were strongly connected to the manufacturing sector, today rely largely on knowledge and understanding. These are economies "in which the generation and the exploitation of knowledge has come to play the predominant part in the creation of wealth. It is not simply about pushing back the frontiers of knowledge; it is also about the more effective use and exploitation of all types of knowledge in all manner of economic activity." (DTI 1998). This spectacular change has been brought about by a number of elements that are both causes and effects of this transformation. Thus, the unequalled revolution in information technologies (ICT) has given birth to an industry with powerful growth dynamics while also offering unequalled opportunities for sharing and exchanging information. In practice, in today's society, enormous and growing quantities of knowledge are produced and made available and the advances in ICT are a key driver in this phenomenon (Bourdeau et al. 1998), so much so that the products of the industrialized economies now integrate significant scientific and mathematical knowledge.

New ways of working, of production and even of learning have come about with the promise of sustainable transformation of our way of doing things. In this new world of rapid change, the success of nations rests more than ever before on first-class human resources, with the competences and abilities required by this new knowledge-based economy. More and more, the knowledge linked to these competences and abilities is mathematical, scientific and technological, paralleling the knowledge involved in the very products of those economies. In this way, knowledge, especially scientific and technological knowledge, has become the principal resource. Consequently, the new strategies for growth have knowledge as the central axis for sustainable development and so improve the quality of life of people. And science is at the heart of this knowledge growth.

science is at the heart of this knowledge growth

The most rapid, wide-ranging and widespread influence that science has had on human society is one of the outcomes of globalization. Everyone, everywhere, is part of the global communication society. The exchange of and access to information, previously reserved for a few, can now be available to all. This revolution has also brought about profound change in the world of work and the knowledge society. From now on, school will have to help students acquire an active repertoire of generic and specialist competences. This differs from the priorities that have governed school subjects such as science until now, where the success of students has been measured in terms of their range of knowledge. Science education has to be a key element in the development of these new competences.

While globalisation offers us challenges, it allows for interconnection between people who until now have been isolated or separated from each other. Section 9 Science and ICT will take on this challenge to suggest some ways that we can move forward.

1.5 Summary

The rationale for science has four dimensions. Firstly, for the foreseeable future, science has a key role to play in helping reduce inequalities. Without a basic science education, people are unable to participate fully as citizens. The second dimension is that basic school science introduces students to one of the great achievements of the modern world. It also makes a particular contribution to developing powerful ways of thinking within science and, more importantly, beyond science. Students begin to acquire a valued and valuable part of culture. Thirdly, in the world of work, basic school science increases the freedoms to choose a wider range of careers, careers that are more financially and personally enriching. The fourth dimension is increasing globalization. This brings with it challenges, potentials and possibilities; to better meet these, students need at least a basic science education.

The Section that follows, explores how these four dimensions can be related to teaching and learning in the classroom to outline a new vision of school science for basic education. We propose substantial developments in the science that students learn in school, with implications for teachers, policy makers and governments. We propose a humanistic school science that will challenge educational systems, not so much in the content of the curriculum but in the way that learning in schools is brought about. We can see parallels with the proposals developed in the accompanying mathematics document. While such changes are challenging, we hope to show that the advantages of these approaches will be such that school science can help meet the challenges ahead. This basic science education will contribute to a more equitable world, where students are prepared to achieve their potential, to contribute to society; students are introduced to powerful ways of thinking about the world. They are prepared to take their full place in that world and to change their worlds for the better.

We propose a humanistic school science that will challenge educational systems, not so much in the content of the curriculum but in the way that learning in schools is brought about

2. Science Literacy

Science literacy, the science that the majority of the population will experience, is the key goal in school science. We will take the advice of Fensham (2008) and go beyond the use of scientific literacy to say what we mean by the terms and how it might look in practice and in policy. We will show that scientific ways of argumentation, knowledge and understanding are necessary for future citizens to take an active part in their futures, namely **education through science**. The students will have an understanding of science that gives a broader view of the world and ways of looking at that world, as well as ways to change their worlds, **education in science**. Students must leave school able to bring together these two aspects **education through** science and **education in** science. That will provide them with what is needed for their future working lives and their ability to take future decisions in food and health policy; the environment and how we can best look after it for future generations; changing energy supplies and sustainable development for all. Quality basic science education should also prepare those students who wish to pursue further studies, jobs and careers in science at all levels, **education for science.**

Science literacy, the science that the majority of the population will experience, is the key goal in school science

2.1 Beyond Science Literacy

In this section, we will explore the changing and changed nature of school science as we try to meet the rationale set out in Section 1. These aims have developed with the changing social, economic and technological circumstances, hopes and expectations of society. Such development will carry on into the future and students must be prepared to respond and contribute to those developments. In his paper for UNESCO, Delors identified four pillars for learning. In line with Section 1, we will elaborate on these , drawing on Macedo (2006); namely (1) learning to live together; (2) learning to be; (3) learning to do; and (4) learning to know. These four pillars help us decide what we should include in scientific literacy for all.

1. **Learning to live together.** School science necessarily implies practical work of different sorts. For a number of reasons, both for managing the class and for good pedagogical reasons, students work in groups to carry out science investigations. Given appropriate

support from their teachers, students can learn that the quality of the outcomes is dependent on the work of all. Taking into account a diversity of views means that together we can go further than we can by ourselves (Baines et al. 2008). Knowing how to present your views and listen to the views of others is an important skill in life and one that group work in science is well placed to develop. Such debates, which necessarily draw on experiences from everyday life, bring in ethical and social dimensions to issues that surround the students and their schools and help them connect the life within their classroom with their lives outside school so helping their science become more applicable. By working together to develop their science knowledge and processes, students are learning to live together.

2. **Learning to be.** School science, through the way it is taught and learnt, should help to develop the way that students and future citizens should act. Science itself has its own values and ways of being and school science ought to parallel these.

   There is a portion of the human mind that good science education, better than any other school subject, can cultivate in school, such as for example

   The spirit of observation
   Calmness
   Self control
   The practice of looking for the causes of things
   Order
   Caution in making claims
   Admiration of nature
   Modesty
   Tolerance and so on (Comas Camps 1925, p. 57).

   This is the issue of values accompanying scientific competences, which we discussed above.

   Such outcomes from science education, combined with those from learning to live together, are a valuable contribution to the development of future citizens. They have to be developed through teaching. Rather than leaving such outcomes implicit as was often the case until now, making such desirable outcomes explicit should make their attainment more likely. Then the student will be better equipped to participate as an active citizen in society, where science related concerns are ever more pressing.

3. **Learning to do.** Through science learning, students will learn to define, refine and resolve problems and ideas. They will learn to do this through practical data gathering, collecting information from a range of sources, transforming that data to make broader

generalizations, explaining their outcomes and justifying their positions. They will start to realize the limits of their data and their arguments and how they might be developed further. They will be developing their powers of logical reasoning and abstraction, a theme that is taken further in the following Section. La Main a la Pâte has shown in detail the benefits of taking an inquiry-based approach. Students are given material to stimulate their thinking and prompt scientific questioning. These questions lead to hypotheses for testing, leading to student learning science concepts and developing their speaking and writing (In French, see Annexes or **http://lamap.inrp.fr//**).

4. **Learning to know.** Students will come to know basic concepts of science, how to use them to explain and understand the world around them, and how to change it. This is the sort of learning most closely related to current school science around the world. However, as we have seen, the contexts for learning these concepts should relate to the lives and concerns of the students, rather than the arbitrary abstractions identified by Fensham (2008). From the perspective of science, students should develop key ideas and understand their interconnectedness, such as the relationship between the macro and micro-structures of materials and their properties, the concept of energy, ideas about cells and interdependence in biological systems. This knowledge is accepted by practising scientists, which they have built on the available knowledge following accepted methods. Scientists also know that science does not have all the answers and that scientific knowledge is continuously under transformation as new information is acquired. As identified above, such knowledge about science is something that should be included in basic science education. A second aspect of coming to know these key ideas is that they are often counter-intuitive. This helps develop more powerful ways of thinking so students are then able to use them in other contexts (See Section 4).

Through these four pillars, students should have opportunities to develop their imagination and creativity as they become active learners. In the longer term, such developments will support the students to lead more fruitful lives individually and as members of future societies.

These changes have to come about within a changing culture of schooling, which take seriously the challenges of current views of school science identified by Fensham (See Section 1.3: Science Education and the World of Work). What it means to teach and learn will have to change if we wish to develop better school science, better matched to science in the wider world. We need to consider what scientific knowledge and concepts we should include in basic education, along with scientific ways of working, changes that will impact not only within the classroom but also the wider school contexts, the homes of the students and their society. Later

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we will address these issues and try to show not only that they are achievable but essential for the good of all.

2.2 Process and Content

The debate about process and content has a long history going back to the start of modern schooling in the nineteenth century (Layton 1979). However, quality science education requires both as well as ways of developing such learning that matches with the aims of Section 1. Programmes such as TIMSS and PISA, that we referred to in Section 1, may imply a universalizing, homogenizing or globalizing of content as nations try to improve their standing in such surveys. However, the ROSE Review (Schreiner and Sjøberg 2004) which covers both developing and developed countries argues that a new school science has to match the context where the students learn. They say such an approach draws on current learning theory, which argues for the efficacy of situating learning in the students' contexts.

> The lack of relevance of the S&T [science and technology] curriculum is probably one of the greatest barriers for good learning as well as for interest in the subject. The outcome of the project will be empirical findings and theoretical perspectives that can provide a base for informed discussions on how to improve curricula and enhance the interest in S&T in a way that
>
> - respects cultural diversity and gender equity
> - promotes personal and social relevance
> - empowers the learner for democratic participation and citizenship, (Schreiner and Sjøberg 2004, p. 6.)

These emphases coincide with the view we are proposing that school science is not something abstract but something that should be connected to the lives of the students. As always, there is the tension between the local, namely student relevance, matching the interests of the students and their contexts; and the wider context, the need to prepare students to go beyond their immediate environment to a wider view of the world and its possibilities. This tension can be alleviated by helping students not only to learn the processes and content of science but also to help them reflect on their learning so that they will be better able to go beyond their immediate contexts. Through their science lessons, students in basic education should learn to search for information from a variety of sources both first- and second-hand; to sort and classify; to explain their findings; to offer conjectures and refutations of their views and those of their peers; to suggest hypotheses; to devise and carry out investigations to investigate these hypotheses, evaluate the outcomes of such investigations, and to be able to bring such material together to bring their work to a conclusion and suggest new opportunities for future investigations. Supporting the students to develop such learning will require a change in the way that many teachers go about their work. The focus is on the learning of the students. We do not underestimate the demands of such a change and we address this in Section 3 Developing the Teaching of Science.

The ROSE Review also reminds us that "Adolescence is not just a preparation for later life, but is an important part of life itself! Students at school should therefore experience this period as interesting, joyful and stimulating in itself" (Schreiner and Sjøberg 2004, p9). This is something that most educators and students would agree with. We should keep it in mind at all times. A positive experience in school is more likely to make for lifelong learning and so for citizens keen to learn more and keen to apply their learning.

Many of the outcomes we have described in this Section relate to how the students talk and write about science (See *Doing Science through Language* in the Annex). For example, being able to argue your case, whether that is in writing or in speaking, puts language in the spotlight. Analyses of such classroom talk offers new possibilities and guidelines for developing quality science learning. Studies show the value of teaching students explicitly how to work, to listen, to talk and to write in groups, small groups of three or four up to an entire class of 30 or 50 (Baines, Blatchford and Kutnick 2008). This takes time in the short term but in the long term the results are impressive. It seems that students who know how to talk about science and, importantly, listen to the science of their peers, are able to have intelligent conversations and acquire the intelligence that is evident in such productive conversations. Students can construct their emerging scientific understanding between equals, offering them the security to use exploratory talk. The way that students also interpret and appropriate such talk from the teacher emphasizes that it is not just what teachers say but how teachers say it (Candela 1999). Such exploratory conversations, focused on scientific ideas, allow students to rehearse their ideas and prepare to share them with wider groups. Such a conversation is a parallel with the way that communities of scientists go about their work. Making explicit such parallels between what happens in class and what happens in the wider world helps the students to learn a more realistic view of science and how scientists work. They are learning about the enterprise that is science. Such debates are frequently of interest in the mass media, for example debates on global warming, an adequate diet, how and when to intervene medically and so on. In these cases we have to reach an agreement within our community, even if it is to agree to differ. At a more mundane level, even in cases where the answer seems obvious for scientists or teachers, such as the difference between a solid and a liquid, when it comes to everyday life and connecting with school science decisions are less obvious. Is potato puree a solid or a liquid

Many of the outcomes we have described in this Section relate to how the students talk and write about science

Through such productive talking and writing, students learn science more effectively and at the same time learn ways to live together, make judgments and decisions, and resolve social or group difficulties

and how can we decide? In other words, talking about science is doing science (Gallas 1995). How we construct a scientific argument is again something that has to be learnt and is a valuable life skill (See Annexe by Pessoa) with the outcomes of research to support us (See for example the journal *Alambique* 63 2010).

Speaking and writing about science is something that has received lesser attention until now. However, the value to be gained from making such processes explicit is important. Here the writing and talking is to develop understanding rather than to tell the teacher what he or she already knows. These modes of doing science, of investigating, speaking and writing about science, show the complexity of the role of the teacher in basic education. However, we have lots of cases where teachers do this successfully in a variety of contexts with few resources and little help. Teachers in basic education also have well developed skills in supporting learning ways to talk and write and so we are often dealing with a transfer of skills rather than developing new skills for teachers. Importantly, as well as such talking and writing being better science education, such activities make an explicit contribution to the development of ways to be an active citizen. They also enable students to be involved in their own evaluation and assessment and so make the most of the possibilities that these developments in assessment offer (See Section 4 Assessment and Learning). Through such productive talking and writing, students learn science more effectively and at the same time learn ways to live together, make judgments and decisions, and resolve social or group difficulties (Baines et al 2008). This is what we mean by **education through science.**

2.3 Science for All

In her presentation to the Experts Meeting on Science and Mathematics Education Policies, Linda King showed that education for all had four essential features.

- **Availability:** that there be mathematics and science in school, in teacher education and with the necessary infrastructure.
- **Accessibility:** accessibility to all, and in particular to women, who are often marginalized.
- **Acceptability:** for example by using the local language in science education
- **Adaptability:** contributing to global issues, as for example global warming, climate change, natural catastrophes, HIV and AIDS.

The findings of the *Education for All Global Monitoring Report* (UNESCO 2009) showed that 75 million children are not enrolled in primary schools; malnourishment impedes learning; there are still gross inequalities between wealthier and poorer children; and that there is a need to recruit, educate and retain millions of teachers. These are important data to keep in mind when we consider what science for all might look like. The work presented above should be the basis for science for all and should also work towards the attainment of the Millennium Development Goals (MDGs). We have argued that the contexts for learning science (food, health, sustainability, living and working together for ourselves and our communities) should provide a contribution from science to the MDGs. So while science in schools should provide concepts, skills, processes and abilities to work towards these goals, that is **education in science,** school science can also contribute to more general aims of education itself – **education through science**. Seeing the beauty of science and developing their creativity and imagination through science should help students become better learners and more willing to carry on learning in science. By learning about how science works, through seeing what they learn and how they learn it, they see the parallels and differences between school science and mainstream science and scientists; students will then be better able to judge outcomes from science reports outside school. Thus they can contribute to those many debates and decisions where there is a strong science component.

Seeing the beauty of science and developing their creativity and imagination through science should help students become better learners and more willing to carry on learning in science.

There is another group of students which we should consider, those who wish to study science beyond basic education. They are important because of the role they will play in a world where science has a key part to play in development. There have been reports around the world to debate such issues. One such was in the United Kingdom, *The Teaching and Learning Research Programme* (www.TLRP.org). This ran from 2000 to 2011 to investigate how to improve outcomes for learners of all ages in teaching and learning in the UK. One major strand of this work was in science education. In the debate about **education in science** and **education for science**, their views were clear about how to develop those with a special talent for science, or wish to pursue science careers at all levels.

Such people share the general need for a broad science education and should not be cut off from it. In any case, there are no valid and reliable ways in which such young people may be identified… **We believe that the best way forward is to provide the highest grade of 'science education for citizenship' for all students**. If that education is sufficiently challenging and interesting, genuine high achievement will become more widespread and will become apparent through students' creativity, lateral thinking, and persistence. The young people who demonstrate such achievement will be increasingly motivated to follow science-related careers, (Gilbert 2006, p4, emphasis added).

This very influential programme saw that good **education in science** for all students would satisfy the need for science specialists - **education for science**. This research programme investigated how to bring about this vision and to develop children's understanding about science and how science works (Osborne, Ratcliffe, Collins and Duschl 2002).

It may be that towards the end of basic education, the students who wish to pursue their studies in science may have a different curriculum. To avoid having too many simultaneous aims and aspirations, Fensham (2008) suggest that we might think of science education having different focuses at different ages and define both essential and desirable basic science concepts. In Science for All, there should be concepts and approaches that contribute to the different dimensions of science education we have specified so far. There are programmes from which we can learn and which provide food for thought when considering particular contexts. For example, there are approaches to science based on a small number of concepts (Science Curriculum Improvement Study, Walsh 2008) as well as those that take an approach based on particular contexts such as science technology and society, citizenship, science and technology, applied science (Salter's Science), environmental science or technoscience. Many of the materials in English are available in the e-library at the National STEM Centre at http://www.nationalstemcentre.org.uk/ This wealth of materials, designed for particular contexts, provides a rich source for the development of appropriate science curricula, a theme we shall return to in Section 3 Developing the Teaching of Science.

The view of quality basic science education proposed is no longer simply an education in science but also an education for science, and an education through science.

The view of quality basic science education proposed is no longer simply an **education in science** but also an **education for science,** and an **education through science.** This new vision should take on the role of catalyst for social change. It should be based on the most valued and shared values of humanity, and influence the way we perceive our relations with others and with the natural and physical environment. These changes imply a reconstruction of school science based on the characteristics of scientific activity. They offer the possibility to frame problems, formulate ideas and explanations, take decisions that can be justified and which allow us to advance. They allow us to act, reflect, question and exchange ideas with others in a collective endeavour based on dialogue and argumentation, where the work of each is for the benefit of all. The challenges that this approach brings, and ways to meet them, are explored in the rest of this document. The next Section discuses what such a science might look like in the classroom.

3. Developing the Teaching of Science

To meet the challenges discussed so far means that there will have to be changes in the way that students learn science in school. The material in Section 1.3 Science Education and the World of Work, as well as surveys by international groups such as the European Commission (2007) found that schooling in science was often related to learning information rather than to understanding concepts and investigating them. They argue for inquiry-based education, as it has shown to be effective in raising attainment across basic education, contributes to increased student and teacher motivation for science, and makes a positive contribution to including a wide range of students through their success in science. In other words, inquiry-based approaches can meet several of the major challenges we have identified above. A major literature review and meta-analysis carried out for the New Zealand Government (Hipkins et al 2002) gave more detailed guidance on what such an inquiry-based approach might look like. They show that the link between theory and evidence is important yet largely invisible for students. Kuhn (1989) shows that this invisibility is one big difference between children's science and the science of scientists. Making the separation and links between theory and practice is something that is best made visible to develop student understanding. Hipkins and Kuhn show us ways to do that. Such strategies are key to linking theory, concepts and practice together. Furthermore, being able to distinguish evidence, to hypothesise, to develop theory and to conjecture are important life skills to which science makes a key contribution. The New Zealand work presents a clear list of pedagogical strategies that meet many of the requirements made clear in Section 2.

inquiry-based approaches can meet several of the major challenges we have identified above

Pedagogy for conceptual, procedural and NOS (Nature of Science) learning in science education could be more effective and inclusive when:

- the existing ideas and beliefs that learners bring to a lesson are elicited, addressed, and linked to their classroom experiences;
- science is taught and learned in contexts in which students can make links between their existing knowledge, the classroom experiences, and the science to be learnt;
- the learning is set at an appropriate level of challenge and the development of ideas is clear – the teacher knows the science;
- the purpose(s) for which the learning is being carried out are clear to the students, especially in practical work situations;
- the students are engaged in thinking about the science they are learning during the learning tasks;
- students' content knowledge, procedural knowledge, and knowledge about the nature and characteristics of scientific practice are developed together, not separately;
- the students are engaged in thinking about their own and others' thinking, thereby developing a metacognitive awareness of the basis for their own present thinking, and of the development of their thinking as they learn;
- the teacher models theory/evidence interactions that link conceptual, procedural, and NOS outcomes and discussion and argumentation are used to critically examine the relationship between these different types of outcomes, (Hipkins et al 2002, p230).

These recommendations mean that we have to rethink how we structure the curriculum in science. Rather than being structured according to the ideas in scientists' science, we need to think of the curriculum structure from the perspective of students' learning and how their ideas might develop to those of standard science. This may seem ambitious, with important implications for stakeholders at all levels. However, evidence shows that the outcomes from such approaches show that they are well worth the efforts for students, teachers, parents and their communities, as well as at regional and national level. By debating their ideas, students can see how the science view of the world matches the view of the world important to their communities. Rather than local views being a barrier, students can see how different world views can enrich their understanding of their world and the part

the outcomes from such approaches show that they are well worth the efforts for students, teachers, parents and their communities, as well as at regional and national level

they play in it. A rich science curriculum can also help students share, develop and extend their experience to take them beyond their immediate environments.

The way that we can help bring this about in the classrooms of the world is discussed in sections that follow. The parallel paper on mathematics argues for very similar strategies. In many schools of the world a single teacher is likely to teach much of the curriculum for the students. Such pedagogy can develop learning in mathematics and science, make links between them more evident, and can be used across the curriculum. The documents annexed to both sections of this Report show further examples in practice and the range of positive outcomes that can be expected. The key actors in this are of course the teachers and we will expand on how we might support change in the classroom in Section 5 Teachers and Science. However, before dealing with teacher development, the subject of assessment and learning will be briefly outlined, which will enrich the debate on teacher development.

4. Assessment and Learning

Assessment is a fundamental part of the work of schools, teachers and students. However, we need to distinguish between the different reasons for assessment and what it is that needs to be assessed. Schools are places of learning and it would therefore seem obvious that learning should be the focus of and the purpose for assessment: assessment for learning. This is assessment that is designed to support the students' learning. Surveys show that much school assessment is not carried out to support learning but it is for other purposes. One common purpose is for the teacher to monitor how far students have gone in their learning. Here the connection with the children's learning is indirect. The results of the assessment can be used to develop the children's later learning. Less obvious purposes, all of them important in supporting an education system of quality include the following, though the list is indicative rather than exhaustive.

that learning should be the focus of and the purpose for assessment: assessment for learning

- to group by attainment to make teaching and learning more manageable
- to select students for particular purposes, the school they might go on to, the suitability for a job,
- to see if they meet the criteria for particular qualifications
- to decide on a suitable type of school
- to see how effective teacher or a school is
- to decide on allocation of additional or scarce resources
- to judge how well a region, nation or educational system is performing, etc.

It is unlikely that a single assessment can serve all assessment purposes. Where the results of the test have high stakes, for example deciding if a student should attend a particular school, or a teacher should lose his/her post, or a school should be closed, it is not surprising that the assessment itself becomes the focus of the teaching rather than the students' learning. While this is obviously a drawback, where systems require such assessments in science, it does mean that science becomes a core part of the curriculum. However, for a high quality science education, the focus should be on the students' learning. Assessments that support learning should be prioritized above other assessments. This may mean that other purposes for testing are downgraded or carried out through different assessment strategies. For an assessment to be valid it should match the purpose or aim of the activities being assessed and the consequences of the assessment should match those same aims. Section 1.3 Science Education and the World of Work shows some of the views of school science held by students. The assessments in science should ensure that the negative outcomes are avoided. For example, assessments focused on recall of information are likely to reinforce the notion that science is transmissive. So assessments need to match the long-term and short-term purposes for science learning. Such matching is an important challenge. There are models shown in the appended case studies which include assessment of concepts, processes and problem-solving. Assessment of values is a field that is not yet well developed and suggests areas for future work.

assessments need to match the long-term and short-term purposes for science learning

In Section 2 we outlined a range of purposes for quality basic science education and it is likely that they need different modes of assessment. One great advantage of developments in assessment for learning is that they have a positive impact on students' attainment (Black and Wiliam 1998, Perrenoud 1998). Most children respond positively and engage more in learning. Assessment for learning usually requires important changes in relationships in the classroom, changes that match the pedagogies outlined in Section 3. Where a variety of types of assessment for learning are brought together, there is better assessment of a richer science education. Such a change can lead to bigger changes across the school, the so called Trojan Horse effect, where an apparently small change, in this case assessment in science, has profound and positive impact on teaching and learning across the curriculum (Kirton, Hallam, Peffers, Robertson and Stobart 2007). Assessment for learning leads to relationships that are more productive for children and teachers in the classroom, and to improved attitudes to learning. As well as improving learning **in science** and **for science**, these relationships contribute to **education through science**, though they take time to develop and will be considered in Section 5 Teachers and Science. One final aspect of assessment that raises a further challenge is timing. Most studies of assessment relate to shorter-term impact, typically during the course of a module or, less often, a school year. The few studies of long-term impacts of learning raise some intriguing possibilities. While it is acknowledged that information retention falls off with time, investigations of teaching and learning where the aim is

Assessment for learning leads to relationships that are more productive for children and teachers in the classroom, and to improved attitudes to learning. As well as improving learning in science and for science, these relationships contribute to education through science

deeper understanding show that long-term outcomes can be better than short-term ones. In programmes aimed at developing levels of thinking such as Cognitive Acceleration in Science or Mathematics Education (Adey, Shayer and Shayer 1994) collaborative group work in science, aiming to include development in students' levels of thinking, shows that longer-term outcomes, several months later, are better than immediate outcomes (Howe et al 2005) So where the assessment is being used for purposes other than student learning, they may need to be used with caution. Such cognitive development is one of the more generic aims of schooling and science seems to have a special part to play as we saw in Section 1.2 Schooling, Science and Culture.

5. Teachers and Science

Teachers are the key players in improving the learning of all our children in school. The large majority of the world's population have experience of being in school and the job of the teacher may seem obvious. However, detailed studies show the complexity of the role of the teacher, especially where the teacher is responsible for the majority or the entire curriculum. Longer-term studies show that to change the fundamental practice takes time. To change classrooms to focus on student learning, as a quality science education demands, is no small task and will require the willing cooperation of teachers, parents, local, regional and national authorities, as well as the students, who will experience a different way of schooling. Not that the suggestion is for a uniformity of experience. Quite the contrary. The argument is for quality basic science education that best fits the local context.

The argument is for quality basic science education that best fits the local context.

5.1 Quantity and Quality

The issue of teacher supply is an important challenge and depends very much on the local context. Generally, in richer countries there are enough teachers to meet the requirements for a teacher for all students, though less so in less developed countries (LDCs). Teachers are often motivated by a sense of service and prestige can often make up for a lower income. However, where the income is insufficient to live reasonably, teachers have to teach extra hours, pursue other work, or leave the profession. Therefore, salaries are an issue. However, this is not a specific science-education issue. What is also of concern in teacher supply is the relative attractiveness of the profession, access to quality teacher education and appropriately supported schools and careers after qualification. Where there is lack of appropriate qualification and low motivation, due to lack of infrastructure such as equipment and laboratories for later stages of schooling, inadequate salaries and career structure, teacher motivation and retention drops (SCPSC 2010).

5.2 Teaching Science for All.

> teachers need support in developing their pedagogical, didactic and subject knowledge for basic science teaching

The second challenge is having teachers of sufficient quality to meet the demands of educating future citizens. There has been progress in moving towards universal primary education, with the consequence of increased demands on educational systems. To meet such demands, teachers need support in developing their pedagogical, didactic and subject knowledge for basic science teaching. As in the parallel report on mathematics, especially in primary schooling, teachers have had little education in science. This is a particular problem in countries where there are numbers of unqualified teachers or where their own education goes barely beyond secondary level. However, compared with the numbers of new entrants, the proportion of teachers already working in classrooms is high and their development will present a significant challenge to all educational systems, both rich and poor. Teachers have a range of knowledge that they use in their work and what might be seen as the most obvious point, teachers' own knowledge and understanding of standard science is the first consideration.

Surveys revealed that serving primary teachers often hold science ideas that did not seem to be in line with the standard science as defined in the curriculum. Logically, it would seem that the more teachers know about the subjects they have to teach, the better it is for all concerned. Newton and Newton (2001) found that higher science background correlated with more subject-relevant interaction (effect size 0.73) and with more causal explanations (effect size 0.65) and these teacher behaviours may lead to better science learning. However, other empirical studies show that the correlation between teaching quality and science subject knowledge accounts for a very small percentage of the variance in teaching quality. Brophy (1991, p350), in summarizing a range of investigations and reviews of the topic came to a clear conclusion.

> *Subject Matter Knowledge* **does not directly determine the nature or the quality of their instruction. Instead, how teachers teach particular topics is determined by the** *pedagogical content knowledge* that they develop through experience in teaching those topics to particular types of students. (Emphasis in original)

Pedagogical content knowledge is the knowledge teachers have about learners and how they learn in a given context. In generalizing from Brophy's work we have to be careful that it is drawn from studies in countries where teachers have generally had several years of post-secondary education and so have some met some essential minimum standards of science subject knowledge. However, in countries where teachers have had less science education of their own, the definition of what this basic subject knowledge for teaching might be is for future research - though completing secondary school science might be an appropriate minimum for teachers in the earlier years of basic education.

What Brophy's study shows is the interconnected nature of teacher's knowledge. While the work of Shulman (1987)[1] has been influential in helping think about what teachers know, Shulman also argues for a more holistic approach with teachers working on case studies to simultaneously develop their own forms of knowledge and teaching. This knowledge development is a dynamic process and should be assessed in the light of how successful teachers are in meeting the goals that are described in Section 2 (Traianou 2007, Macedo 2006)

By starting in initial teacher education with this case study approach, teachers can see how their knowledge interconnects. Teachers who can make connections between ideas and process across topics seem to have students who learn more science and better science (Novak and Gowin 1983, Hipkins et al 2002). As Traianou shows, this form of interconnectedness is something that teachers start in their initial teacher education and can continue to develop whilst teaching (See Section 8 Spreading Good Practice). Such development can be done by individual teachers but is much more powerful and efficient when done with other teachers through continuing professional development, particularly where teachers are involved in developing, testing and investigating new ways of working in science (Black and Harrison 2004, Baines et al. 2008). This benefits not only the students' learning but has positive benefits for other stakeholders too (Clarke and Ryan 2007).

Such development can be done by individual teachers but is much more powerful and efficient when done with other teachers through continuing professional development, particularly where teachers are involved in developing, testing and investigating new ways of working in science

One important outcome from such research in many countries is the key issue of classroom climate and teacher student relations. Nieda and Macedo (1997) offer a succinct summary of the outcomes of this research.

- Teachers have high expectations for all the students in their class and are able to convey these expectations to their students.
- The more the students are involved in their tasks the more the outcomes increase, provided that the tasks are within the reach of students and of their peers working together.
- There is good classroom discipline with norms agreed with the students through negotiation.

1 See also the discussion in the mathematics report.

- There is ongoing assessment for learning (See Section 2 Assessment and Learning).
- There is ongoing whole school-development focused on student learning agreed by the school staff.

This emphasis on the value of good case studies is one reason why there are cases annexed to this report. Cases show how the various challenges identified in Section 2 can be met in the realities that teachers, schools and educational authorities face in the complexities of the classroom. The writers of such cases are clear about how the various factors have played out in their context. It is for the reader of such cases to see how they might take the ideas and thinking to match it to the reality of their teaching. Such cases emphasize the value of giving teachers room to develop their teaching and the students' learning. Only where the teachers have some such space can we expect students to experience the artistry, awe and wonder described in Section 2 as part of a good basic science education (Clarke et al 2007).

> Only where the teachers have some such space can we expect students to experience the artistry, awe and wonder described in Section 2 as part of a good basic science education

One final challenge is the need for stakeholders to be sure that teachers are increasingly able to meet the challenges of helping students develop a good basic science education. The issue of teacher assessment is much less well developed than is the assessment of student learning. The results of such assessments can have important consequences for individual teachers, schools and systems. This makes it more obviously political and, as with student assessment, should match the goal of the assessment. Studies such as TIMSS and PISA show how systems might be evaluated. Where the evaluation of individual teachers is considered, then the benefits of assessment for learning suggest positive ways to support teacher development. As with students, where high-stakes testing of teachers is developed, it is likely to lead to "working to the test" thus decreasing the creativity, joy and wonder that students should expect from their basic science education. Surveys of teachers show that they are well able to define what they need and what they would like to know and be able to do. They are aware of the daily classroom dilemmas of what sort of science they should teach, what students' science ideas are and how they can work with them, and the ways they can help students' cognitive development (Leymonié Sáenz et al. 2009). This suggests that if we take teachers seriously, then they are ready to move towards the quality basic science education we have outlined in Section 2.

6. Working with Others

Individual teachers or schools can make significant progress in their particular contexts. When it comes to wider developments the case for all stakeholders acting together is clear. Expertise of different sorts is needed to support developments in quality basic science education. For example, scientists are best able to ensure that the connections between key concepts are made clear and fit well with standard science. Making such connections evident in classroom materials means that teachers are better able to make them evident for students. Different sorts of expertise are needed to transform these connections into ways to help students to learn. We can see the value of using different sorts of expertise in this enterprise. Where science education research projects have included teachers, scientists and science educators, there have been powerful, deep changes in students' science learning (E.g. Baines et al 2008). However, we have to bear in mind that in many countries the numbers of scientists is relatively small and they already have a wide range of demands placed upon them (Albornoz 2001) so we have to ensure that they are used effectively. Such work by professional scientists also needs to be recognized within the community of science and in the universities and institutes where they work. Powerful cases of such collaboration between scientists, science educators, teacher educators and schools are given in the annexes to this report.

Where science education research projects have included teachers, scientists and science educators, there have been powerful, deep changes in students' science learning

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Quality basic science education does not exist in isolation in schools. Outside schools there are many contexts where students meet and learn about science such as television, films, newspapers, museums, the internet and so on. We will develop this topic further in Section 7 Science beyond the Classroom. Increasing interest in science careers is not simply a challenge for schools. Scientific organizations and associations of professional scientists rise to this challenge by providing resources for schools, frequently subsidizing materials or making them available on the internet. For example the Astrazeneca Science Teaching Trust (2010) has produced modules for teachers to use to develop their science teaching with the aim of supporting an approach to science learning consonant with the views of Section 2 (Clarke et al, 2009). They are aware of the growing need for scientists at all levels and of the declining interest in science and wish to deal with these trends. While their aim is to increase the number of people wanting to take up science careers, they realize that the best way to achieve this is through the view of science presented in this report.

While much basic science education can be learned using everyday materials, there are inevitable costs in doing this

While much basic science education can be learned using everyday materials, there are inevitable costs in doing this (Harlen 2008). Access, as we have been discussing it, also includes access to resources. A curriculum founded on the principles and ideas we have outlined above would certainly include practical activities, which necessarily means material and equipment beyond the everyday. This means that there are implications for school authorities in the provision of science resources, with consequent work to convince politicians and officials to make these funds available.

Communities and countries rely on an adequate supply of trained scientists at many levels from laboratory technicians to pure and applied scientists (Albornoz 2001). It is in the interests of countries and regions, as well as the interests of students in basic education, to promote the benefits of a wider career choice for parents and their children as a consequence of studying science.

7. Science beyond the Classroom

Learning outside the classroom and outside the school has important contributions to make to science education. The case for schools working with other agencies is powerful. Data from TIMMS and PISA shows the impact of science outside the classroom. Students show that they have knowledge and understanding about science topics that have yet to meet in their formal schooling. This implies that they have learnt this science knowledge outside school. The work of science centres and museums around the world show many creative ways to support science learning (e.g. Plant Science Network 2008). For example, there are over 2500 botanic gardens around the world with facilities that schools can use (Botanic Gardens Conservation International 2010) and often there are dedicated staff to support teachers in students' learning of science.

Apart from science museums, many organizations and companies provide resources for schools, from material resources to visiting experts. Such experts might be working scientists or expert members of the community who might not see themselves as working scientists: the barefoot doctor, farmers, veterinary support workers and so on. The use of such experts working in ways that we identified in Section 2 was pioneered by the Learning in Science projects in New Zealand (Bell and Gilbert 1995). These projects provided models of how to deal with major science concepts, such as energy, which take into account children's ideas and then use an investigate approach to exploring these ideas. They give a powerful argument for the use of experts in this approach as a way of comparing "children's science" with standard science and helping students to appropriate more powerful ideas and concepts. The use of these powerful ideas in everyday contexts is at the heart of the PISA concepts of 'scientific literacy', an important facet of quality basic science education. Such interactions with experts show science literacy in action and helps transfer learning to contexts outside the school, a very desirable outcome for science education. Where few experts are available, schools may make use of outside expertise through the internet (see Section 9). Informal science education is a rapidly developing field, as shown by studies on learning in science museums, the increasing numbers of science museologists, and the realization that science museums help create a growing awareness

interactions with experts show science literacy in action and helps transfer learning to contexts outside

of the importance and value of basic science education. Informal science has developed approaches such as theatre, drama, performances, festivals, science cafés and so on. A review of these approaches is beyond the scope of this report (See Rennie 2007). Their approaches also help us in finding ways to help spread quality science education beyond individual projects.

8. Spreading Good Practice

The many curriculum projects in school science in the 1960s and 1970s generated a wealth of resources yet did not lead to a great change in practices. At the time, the feeling was that producing such resources would help teachers bring about profound changes in the classroom. Recent studies show that such profound change requires a different approach. New materials may be necessary but are not sufficient to change behaviour significantly. Fensham (2008) shows how the issues of policy, practice, assessment and research were often treated as independent rather than interconnected issues. He argues that where these different aspects develop together in an orchestrated fashion then they are more likely to lead to real advances in the curriculum and classroom pedagogy. However, where researchers frame the outcomes of their work in terms that relate to the issues of the different groups profound changes can come about in both thinking and practice. For instance, the work of Black and colleagues on assessment for learning, much of it carried out in the context of basic science and mathematics education, seems to have had an impact because they wrote about the outcomes of their research in different ways for a variety of different audiences (Black and Wiliam 1998). When leaders of local authorities and schools saw the outcomes expressed in terms they understood, they were quick to advocate the approaches suggested. However, what subsequent studies show is that classroom adoption requires sustained effort and support for teachers over about a year, with the costs in a research and development context being something like 8% of the cost of an annual teacher's salary. The outcomes are better science education and better attitudes to science for both students and teachers. In addition, the approaches act across the curriculum as the changes introduced alter relationships in the classroom and school and lead to better learning across the curriculum. While such research and development costs may be thought of as acceptable in business development, in schools we will need research on the relative costs of scaling up approaches to innovation.

classroom adoption requires sustained effort and support for teachers

Involvement of teachers in curriculum research, development and innovation provides them with an understanding of the projects, of what they are trying to achieve and how they are trying to bring about change. This teacher understanding, missing in the projects of thirty or so years ago, is seen as key to helping teachers do the necessary adaptation of the materials to their particular contexts. The collaborations between teachers, researchers and curriculum developers bring benefits to all these groups and especially to the students in the classroom. By creating a range of options, including spaces for teachers and students to grow, scaling up is likely to be more effective (Gass 2007). Working together, each of these groups can contribute to the development of each of their respective fields of classroom practice, of curriculum development and of research in pedagogy and didactics (Annexes and Black and Harrison 2004, *Main a la Pâte* at **http://lamap.inrp.fr//**). Where 'teacher-proof' materials are developed and their adoption required, initially there is a tendency for the superficial features of classrooms to change followed by an eventual return to the status quo (Cordingley and Bell 2007). Rather than seeing the adaptation of materials to specific contexts as shortcomings, researchers now realise that such adaptations are necessary and lead to better materials, better resources and better student learning (See case studies in the Annex). Classrooms thus become spaces where all can grow - both teachers and students.

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A novel approach to spreading good practice, the Colombian *Expedición Pedagógica* is to take an Appreciative Inquiry approach (Reed 2006) to recording the ingenuity teachers show in adapting national requirements to the local situation. The scheme has collected some 3,000 accounts of teachers and their practice to show how the diversity of situations and teacher creativity and resourcefulness shape classroom practice. Many groups of teachers, often with parents, researchers and teacher educators, have come together to develop their practice in ways that are described above. Such groupings help develop a clear, mutual understanding of what they are doing and why they are doing it. The range of materials that teachers have produced is impressive,. They show how classroom practitioners can develop and share the results of their activities, and how such appreciative approaches act as a powerful form of teacher development (Unda Bernal et al. 2003).

In the commercial world, different people are expected to need different products to suit their circumstances. The same also applies to health provision. Perhaps in education, we should also expect a diversity of supply. If a teacher were to take a particular approach to teaching a topic such as renewable energy and the students did not seem to be responding as the teacher hoped, then he or she would automatically try a different strategy. Teachers thus personalize their students' learning by adaptation to local needs on the ground. It may be that at system level there should be an expectation of diversity rather than uniformity. The issue of how to take projects to scale so that the benefits of different approaches can be made available to all, should become a focus for research and development efforts (Horner and Sugai 2006). A detailed agenda for such research and development, which applies equally and simultaneously to science teaching, is given in the accompanying Mathematics Report.

9. Science and ICT

The challenges of globalization, the links between the development of the knowledge economy, new technologies and science ideas have outlined. While globalization is sometimes seen as a threat, in the field of education and science teaching and learning in particular, it raises possibilities for growth and development in teaching and learning. New technologies offer a wealth of information and resources for teachers and students. This trend is likely to increase in the medium term and offer an invaluable resource for learning. However, teachers will need to learn how to select, adapt and use these resources to suit their purposes. This poses a significant challenge.

globalization raises possibilities for growth and development in teaching and learning

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One obvious benefit for the classroom is the use of the Internet and the range of materials that are freely available to support teacher learning as well as materials for use in the classroom. Sources such as www.youtube.com/education or www.diffusion.ens.fr among other websites, offer materials to support teacher training. Many of the science museums of the world have websites that offer support in developing both scientific processes, and science knowledge and understanding, for example www.exploratorium.edu/ or www.cite-sciences.fr. Often such sites offer the possibility to consult a scientist about students' or teachers' difficulties to meet inevitable challenges in the classroom (e.g. http://askascientist.org/). Such facilities are particularly important when dealing with the science of everyday life and the way that scientific ideas apply in different circumstances. For the non-expert, which includes most teachers, faced with the rapidly expanding knowledge of science, the issue is usually deciding which scientific ideas to use to explain everyday phenomena. Once the appropriate ideas are made clear, understanding becomes much easier.

Other digital technologies also offer possibilities in the science classroom. With increasing availability of internet access, and projects such as *One Laptop, One Child* (One Laptop 2008) or *Plan Ceibal* in Uruguay, issues of costs are being addressed. While such schemes may be ambitious, they indicate possible future directions. Individual computers offer the possibility for developing generic learning as well as specifically scientific learning and engage the students. Digital technologies can help develop learning in science processes. They can support students with data collection, data analysis and presentation. By removing some of the routine and mechanical aspects of such processes, students can be helped to develop the higher skills of data interpretation and evaluation (Frost 2009). Video technologies allow students to record processes that are too quick for the human eye to see or too slow to record carefully, such as what happens when a ball bounces or the details of seed germination or plant growth. Simulations and materials on the internet can allow students to try virtual experiments where the equipment is too costly, or the outcomes too risky or dangerous. The rapid feedback reinforces student learning, and removes some of the burden of being seen to be wrong (as when students respond to their teacher). However, Toyama (2009) reminds us that the provision of equipment is only part of the solution. The appropriate use of these resources is vital, as is the essential support and maintenance of the hardware, among other issues.

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Quality basic science requires quality resources both for teachers and for students. In many countries, educational research is producing materials supported by government finance and there is a growing trend for such materials to be freely available on the internet. This provides some surety that materials have been tried and tested and it is left to the teacher to adapt them to their context. This adaptation provides challenges for science teacher education, which must prepare teachers to make such changes.

Supporting student use of information on the internet, creates new roles for teachers. There are quantities of information and materials available which were unimaginable twenty years ago. However, information is not the same as understanding. Information has to be grasped, interpreted, applied and dealt with in a way that may require new competences. This understanding, whether they be of the 'what', the 'why', the 'how' or the 'who', are developed by the process of research, which contributes to human experience (MRST 2004).

> students and teachers will need to learn skills of classifying material, evaluating information and checking the arguments that the materials offer

Thus the digital divide, which refers to the differential access to the means of obtaining information, especially ICT (both access to the equipment and access to ways to use the equipment) has now been replaced by another divide. This second divide is built upon the ability to search, interpret, deal with, produce and disseminate understanding and especially to be able to use technology confidently, in a creative way. This ability can be used in order to generate new ideas or novel solutions to complex problems, and allow the user to join networks (often international ones) of sharing and acquisition of knowledge (Nasseh 2000). Students will need to acquire such skills to achieve their potential as people and as citizens

A particular scientific use of such generic skills is in developing scientific processes (See Section 2.2 Process and Content). The quality of science-related material varies widely so students and teachers will need to learn skills of classifying material, evaluating information and checking the arguments that the materials offer. Does the material offer information or data and how reliable might that be? Are there hypotheses being suggested or tested and how are the outcomes used to generate deeper understanding? There are also web pages, for example Ben Goldacre (2010), which provide models of scientific reasoning relating to current issues such as nutrition or neuroscience and learning. Students and teachers can use these to develop their scientific reasoning and so be better able to analyse other studies that appear in the media. Such activities will also help students understand the difference between data, hypothesis and theory, a valuable skill to take into adult life.

10. Collaboration across frontiers

The advances that science has brought to ICT make international collaboration in science and science education a possibility that was unimaginable for a previous generation. There is a wide range of bilateral arrangements, building on historical links. Many of these now have a virtual component, and include teacher education as well as student education. At a regional level, centres such as the *Centre for Mathematics, Science and Technology Education in Africa*, Nairobi, Kenya, are working to increase the quality and quantity of school science and the training of science teachers. The outcomes of such groups' activities provide valuable material for other regions to consider. For example, before the November 2009 meeting of Ministers of Education of the MERCOSUR and associated countries in Latin America, the preparatory meeting recommended that new science policies be developed.Amongst other aspects, they recommended these policies should include the context-specific nature of science education, that there be a right and a duty to continuous professional development for teachers, supported by virtual networks (Ministerio de Educación y Cultura 2009) Such recommendations chime with the approach suggested above. We should point out that while teachers' right to professional development is not especially new, the decision to recommend it as a duty is. This would put teachers in line with other groups such as doctors who frequently include in their version of the Hippocratic Oath the need to keep oneself up to date with new research, developments and best practice.

they recommended these policies should include the context-specific nature of science education, that there be a right and a duty to continuous professional development for teachers, supported by virtual networks

In China, the *Learning by Doing* approach to science education (Wu Yei 2009), developed with colleagues from France, advocates the inclusion of science as a core subject in basic education from kindergarten. Other networks deal with particular issues such as small states and the construction of suitable resources for education and development (The Commonwealth of Learning, 2008). The network hopes that the development of such technologies will help deal with the task of meeting the challenge of developing science education in Africa. We should not ignore the many less formal structures that exist. Regional conferences in basic science education bring together interested parties to work on common problems. In some of these, such as the Iberoamerican Conferences on Science Teaching, participants include university and local authority partners and a large proportion of teachers, who report on their research and development work. These conferences support many formal and informal connections across frontiers for their mutual enrichment.

There are also school-to-school connections and networks. "Science across the world" (www.scienceacross.org) encourages students to explore science locally and share their insights globally. At the time of writing, 8,305 teachers in 149 countries were supporting students collaborating on school science topics. The project claims a number of outcomes in line with some of those identified above. These include students who are motivated by working with others across the world. Students can see topics such as health or nutrition in a wider context. They develop communication and interpersonal skills. They show remarkable creativity in thinking through and evaluating their projects as they explain their findings to people with different backgrounds. Teachers develop professionally as they extend their science work into important areas such as citizenship and sustainable development education. Students also begin to appreciate the impact of languages on science and its communication.

11. Meeting Diversity

11.1 Language Issues

This Section deals with two main aspects of language and science learning, learning to speak and write the language of science and meeting the demands of learning science in languages other than mother tongue or home languages. In English, early work in science education research often focused on the language demands of learning science (Sutton 1992) and continues to develop including the realization of the multi-modal ways that students learn science. Scientific language has specific demands. There is an extensive vocabulary to learn. Some studies show that the vocabulary demands of some secondary school science programmes are greater than those of second-language programmes (Williams 2009). This is clearly expecting too much, particularly if the language of instruction is not the same as the students' home language. There have been many studies on how science uses this vocabulary in ways that tend to be different from everyday language use (Halliday and Webster 2006). The emphasis here on basic science education, on understanding rather than simple reproduction of information, means that students should be using the language in which they feel most comfortable, especially when meeting new ideas. They should be developing understanding first and technical vocabulary second.

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The language challenges vary within and between countries. In some countries such as Bolivia, where there are several official languages, teachers are expected to be at least bi-lingual. Such language skills mean that early or basic science education can be in a language that reflects the local community. However, this solution does not solve the many, often delicate issues of language diversity, and their connections with social class and ethnicity. It is beyond the scope of this report to try to attempt an answer. The ***Science across the World*** project mentioned above has some suggestions for science contexts and the UNESCO Position paper (2003) clarifies the challenges of bilingual and multilingual education. It remains for research to see how these play out in the context of basic science education. Perhaps a particular focus should be rural areas. Language, class and socio-economic status all combine to reduce the freedoms and possibilities of children in science (Guadalupe 2004). This is especially urgent as major issues of sustainability and global warming will affect the poor more heavily than other sections of society (DfID 2009). They therefore have a special need for the sort of quality basic science education we are advocating.

11.2 Gender Issues

The issue of gender in science education again has been the subject of many investigations. This is an important concern for both the individual students involved and their communities. International studies such as TIMSS and PISA show that the higher-attaining countries are those where there is less inequality. Gender equity is a long-time concern for UNESCO. For a variety of historical and cultural reasons, girls have tended to be underrepresented in science education. Wherever there are choices to be made, girls seem not to take up or be able to take science options. The view of basic science for all of Section 2 should go some way to removing some of the barriers to equal participation. Studying science in everyday contexts makes for better science for all and is less likely to raise barriers to girls' participation. Indeed, in some contexts where science is compulsory in basic education, girls' attainment is higher than boys', a change that has occurred over the last 20 years. However, the way that such attainment is achieved may present more powerful longer-term outcomes for boys than girls (Bell 1997).

International studies such as TIMSS and PISA show that the higher-attaining countries are those where there is less inequality.

In other contexts, it is not simply that the quantity of science education is different. Asimeng-Boahene (2006) shows that in many parts of Africa, girls also receive a science education of lower quality than boys. She suggests detailed steps that teachers and school authorities can implement to reduce such inequity. This presents a challenge for initial and in-service teacher education. Teachers need to know the sources of such inequality and how to overcome them so that there are more equal outcomes for all. Steps to improve the education for some seem to lead to the improvement of education for all.

12. The Challenge for Research.

The need for the involvement of all stakeholders in such processes is clear

The proposals we have made so far are based on a reading of research and practice from around the world. We have also argued for the need for the curriculum and for classroom practice to be connected to the everyday reality of the students. There have been many advances in understanding students' views about science, its concepts and processes. The outcomes of such research now need to be translated into practice as suggested above and as the case studies show. While the evidence for these proposals is powerful, there is a need to research the way that they play out in wider contexts. The transformation of knowledge from science into powerful ideas that students can learn is an area for further development. The need for the involvement of all stakeholders in such processes is clear; collaboration between experts such as classroom teachers, practicing scientists, science education and curriculum development researchers, parent groups and school authorities is vital if we are to avoid the mistakes of the past and to develop quality basic science education for all children. We have to be aware of the gaps between the written curriculum, the planned curriculum, the learned curriculum and both the short- and long-term consequences of students' learning. Fensham (2008), in Section 1.3 Science Education and the World of Work and from Hipkins et al (2002) in Section 3 Developing the Teaching of Science, provide further areas for investigation as these changes move to new contexts.

The developments we have presented have been in typical classrooms and, by definition, part of larger research and development projects. What remains to be done is the vital challenge of addressing such innovations in less favourable contexts and work towards defining ways that innovations can be taken to scale. This work should involve colleagues working in the wider context of the whole curriculum, especially when dealing with issues such as learning through science, and talking and writing for learning.

As Stenhouse reminded us many years ago, there can be no curriculum change without teacher development. Quality basic science education therefore necessarily implies significant continuing professional development. The value of such professional development including teachers' involvement in research, development and innovation is clear. Many teachers are working in challenging circumstances and show remarkable creativity in meeting the demands of supporting the learning of their students. If we start from a positive view of what teachers can do and build on the ingenuity and creativity of teachers, then classroom change will be easier. As an example, the Expedición Pedagógica in Colombia has shown a way that teacher learning and professional development can be achieved as well as significant changes in classroom practices at relatively low financial cost. As Stenhouse further reminds us, until now "perhaps too much research is published to the world, too little to the village" (Stenhouse 1981, p.17), reminding us of the need for involvement of parents and leaders of the school and the local community. The internet offers possibilities for such outcomes also to be broadcast beyond the village to the world. It may be that UNESCO has a role in coordinating such broadcasting. The interactions between these parties and their views of the curriculum would be a further area for work.

"perhaps too much research is published to the world, too little to the village"

The difference between researching such changes and monitoring and evaluating demands on the system at different levels identifies further areas for research. Education is an expensive undertaking and we all need to be sure that it is working towards the aims spelt out in Section 1. However we cannot expect one sort of assessment to cover all needs. There need to be developments in the assessment of values and the work of teachers. The lessons from assessment for learning, formative assessments, offer possibilities for ways that might frame such research.

The proposals we have made help set an agenda for research at classroom, teacher, school, community and national level. The outcomes should be written for different communities with a stake in education in terms that are clear to them so all can learn.

13. Summary

The benefits of involving a wider range of people in curriculum research and development are now clear, even though there is much to learn about spreading research project practice to entire systems. While this is an important and difficult challenge, the evidence is that where it happens everybody involved can benefit, students, teachers and the wider society. That children learn better makes the effort of meeting the challenges worthwhile.

The most important resource undoubtedly is an adequately and appropriately educated teacher. The main challenge is to find and educate sufficient teachers in the process, as well as the content, of science, its curricular approach and appropriate didactics and teaching approaches. This challenge may seem too demanding for the realities of some countries. However, we have sufficient cases from around the world of teachers working in the ways we have outlined to suggest that our ambitions are achievable. Our aim is above all to do things differently, rather than demanding more. These teachers will also need access to, and be committed to, in-service education, to continue their professional development. This means that countries and regions must have such a system available with incentives to support it.

The main challenge is to find and educate sufficient teachers in the process, as well as the content, of science, its curricular approach and appropriate didactics and teaching approaches.

The final challenge is to educate stakeholders, beyond members of scientific communities and researchers in science education, to include representatives of business and commercial groups, politicians, parents and local and national authorities. This involvement is essential for the support of teachers and students and for a renewal of the curriculum, both national and international.

Six key factors come to the fore. The first is a curriculum based on science as process rather than a product, with the focus on deeper learning. The second factor is adequate and appropriate teacher education, as basic education crucially depends on the person who brings about the curriculum, whether present in the classroom or a remote or virtual teacher. Thirdly, we need to adopt those strategies that support such a vision of science education. International investigations and specialists all point to the value of Inquiry Based Learning as a key way to bring about this vision of science. Fourthly, we need to add complementary strategies and actions that improve equality of access for groups such as girls, the poor and minority ethnic groups. Fifthly, we need to be aware of the factors that help increase the numbers of students who wish to follow careers in science. The sixth and final factor is the need to involve actors from outside the school system. In some countries, access to science learning outside the school, or informal education seems to be an important factor in learning. Taking a more systematic approach, the involvement of scientists in basic education adds considerable value. The work done by local and international associations of science education in investigating, innovating and developing science in schools cannot be underestimated. Each of these six factors need to be considered in the light of evidence and researched further as changes happen.

From the point of view of the rights of the students, the issues of availability, accessibility, acceptability and adaptability are essential. Without these, there can be no quality education. The consequences of a science education in the long-term – to be able to participate in the variety of human activities and meet the challenges to society emphasise the importance of education through science. The proposals we have made should contribute to this challenge through developing new relationships between teachers and students, where knowledge is no longer the source of power for a few, where science is not an absolute but the fruit of the work of men and women across ages and cultures to which all can contribute. We hope to create educational spaces where science is seen as linked to the issues surrounding the lives of all women and men, their ways of being, their ethics and aesthetics, and the cultural, social, economic and political contexts where they can thrive.

Savater (2004) points out that many in education are inclined to see the difficulties. However, he also points out that education presupposes an optimistic view of human potential. If we have faith in the potential of all involved in education, then we can bring about this vision of quality basic science education for all.

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Annexes

In these Appendices we use some case studies to illustrate the ways that the ideas presented in the main text have been turned into successful practice. These cases show how they impact on children's learning in science, through science and for science. They show how networks, groups and associations can combine for the benefit of each of them. They also give some idea of the time scales to produce real change in the classroom with the projects running over several years. We hope that these approaches will inspire others to take them, adapt them to their particular contexts and so enrich and enhance the learning of teachers and of future generations of school children.

Annex 1. *La main à la pâte* 1996-2010: Implementing a plan for science education reform in France

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Summary. *La main à la pâte (Lamap)*—learning by doing—is an inquiry-based science teaching program launched in 1996 by Georges Charpak, winner of the Nobel Prize for Physics in 1992. The program was immediately supported by the French Academy of sciences (*Académie des Sciences*), which has managed it since then with the help of the National Institute for Pedagogical Research (*Institut National de Recherche Pédagogique*), and the *Ecole Normale Supérieure* (Paris). In 2000, the French Ministry of Education decided to implement a 3-years ambitious "national plan of renewal of science teaching" at the primary level, inspired by *La main à la pâte*. Since then, *Lamap* continues to innovate, to support teachers and contribute to the elaboration of new national standards and best practices for science education in France, moving in 2006 from primary to middle school (grades 6 & 7). The *Lamap* story is an example of how the initiative of a group of scientists, gathering many partners, was able to contribute to the transformation of science education in a highly centralized educational system and to rapidly collaborate at international level with many countries.

The early days. In 1996, education in natural sciences in French primary schools (pre-school, then grades 1 to 5) had almost disappeared, despite its formal presence in the curriculum. Education authorities exclusively focusing on reading, writing, counting, as well as the lack of teacher training and proper understanding of science by them explained the situation. The *Lamap* movement began within the scientific community, which strongly supported it and immediately established a fruitful collaboration with education authorities and some didacticians. An authentic science vision and an inquiry pedagogy goal joined to implement progressively a new science practice in French primary schools (Sarment et al 2010). As early as 1998, this practice was expressed in *Ten Principles* and these guidelines proved to be extremely useful and efficient in the long term[2].

2 See the *Ten Principles* at www.lamap.fr/

Although by then some researchers had already felt why *science education for all* was essential, *Lamap* was probably among the first ones[3] to propose justifications which in 2010 are widely accepted and were then expressed in this order of importance : cultural value of science including mastery of language, role of science education for citizenship and in the globalisation context, justice in sharing with all youngsters science and technology progress, preparation for scientific and technical careers. *Lamap* insisted on the value of science lessons beginning at an early age – possibly in pre-school –, a view broadly accepted in 2010.

In these early days of *Lamap*, it was soon realized that a good curriculum did not suffice to implement and transform teaching practices. Implementing inquiry required a diversity of new ingredients, in order to help teachers. A rather original cooperation arose, where a large permanent team within the Académie des Sciences was formed, elaborating resources for the classroom. The *Académie* concluded a long-term cooperation agreement with the national education authorities, supporting the effort and setting a common and ambitious goal for improving science education in primary schools all over France. This set-up guaranteed the independence of the effort, which could be less subject to political fluctuations and funding issues, while it gave to the action in schools a necessary official recognition. In addition, it allowed a bottom-up methodology, where teachers could directly be in relation with a national, respected and independent body, led by scientists and science educators.

The national impact. After pilot projects were carried in a few hundred schools, a national program (2000-2003) provided new resources to all schools and a new curriculum (2002) was adopted, recognizing inquiry pedagogy as optimal for science education. At the national and regional levels, the program was organized to coordinate the activities of directors of education, inspectors, institutes for vocational teacher training (IUFM), and scientific institutions (Ministry of Education 2000). Some national workshops were organized.

A typical *La main à la pâte* lesson follows the inquiry principles, today widely accepted. It begins with a question, where the teacher quizzes the children about inert objects (such as rocks, water, and the sky), living beings (insects, the human body, and plants) and natural phenomena (winds, tides, and climate), asking "What do you think?", thus inviting them to advance their own hypotheses. Investigation, free expression, argumentation in groups, experiments develops reasoning, while writing in a science notebook helps language acquisition. Children, boys as well as girls, develop their curiosity, acquire a new awareness of the utility and explanatory powers of scientific principles and the logic of science, they discover the virtues of teamwork and acquire the skills needed to prepare and carry out an experiment.

3 *La main à la pâte* has always recognized the inspiration it received from efforts already on the way in United States, especially Leon Lederman in Chicago, Karen Worth at Education Development Center in Boston and Bruce Alberts then preparing *National Standards* with the National Academy of Sciences in Washington D.C.

To implement such a pedagogy, which for many teachers seemed entirely out of reach, not to speak of their often naïve vision of science and fear of hands-on experiments or open questions in the classroom, a great amount of efforts, still going on in 2010, had to be undertaken in order to help and coach them. These included : accompanying scientists (e.g. students from engineering schools), elaboration of inquiry resources jointly with teachers, pilot schools or districts to experiment and validate new resources, large scale diffusion of resources using Internet, public visibility of the actions on media to associate parents and local communities, etc. (See website for complete list) Special efforts were made to "reconcile" teachers with science : in-service training avoided formal lectures and preferring teachers to carry inquiry and experiments, as they would require children to do. It amazingly awakened teachers' curiosity, which for some of them had been asleep for a long time,

Since the end of the national priority given to science in 2003, progress has been constant although slow. In 2010, it is estimated that about 50% of primary schools follow more or less the new science curriculum, but only 10% of teachers are able to apply inquiry teaching, with a continuum of classroom practices existing between *full* practice and *really inadequate* ones (Saltiel and Delclaux 2010).

In 2006, a "*Common base of knowledge and skills*" (*Socle commun de connaissances et de compétences*) was incorporated in French law and education regulations. It sets the required competencies throughout and for the end of compulsory education (age 16), which in France is identical for all students, and ensured continuity between primary and middle school. This occasion was seized, again by the Académie, to implement an experimental program of integrated science and technology in middle school, following many of the *Lamap* principles (See **www.science-techno-college.net**).

Assessment of the middle school program (students as well as teachers) has been carefully completed and is very positive, though we await a complete, thorough, nationwide evaluation of the primary school program. Only fragmentary observations and research demonstrated parents and communities support, teachers continued involvement and continued growth. From 2009 on, in accordance with *the Common base of knowledge and skills*, students will also be tested on practical skills and social behavior as well, and the benefits of inquiry learning already appear.

The international networking. Since 2000, the concern on early science education has been growing worldwide, and the Académie des sciences, in connection with InterAcademy Panel education program, has progressively been involved in many collaborations to organize local training sessions or visits in France and to disseminate the *Lamap* tools, properly adapted to local situations (See website). This networking developed along several routes, involving science Academies and/or national ministries, and deals in 2010 with over 60 countries. The support of the European Commission, focusing on the goal *of a society of knowledge*, brought since 2003 increasing resources to disseminate inquiry practices in Europe (Léna 2009), in projects closely associated with *La main à la pâte*.

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Annex 2. Networks and practice communities for improving motivation and learning in science & technological education

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Introduction

The vertiginous scientific and technological advances have a special force in developing the knowledge society, permeating our daily life and raising challenges for citizens and in the world of work (Roberts, 2007). Consequently, scientific and technological literacy *for all* constitutes an essential purpose for scientific and technological education, especially in basic education systems. Paradoxically we are witnesses of science decline in the education context (Castaño *et al*., 2006). On worldwide scale and mainly in the West, there is a worrying trend of declining student interested in science studies and science education. Statistics indicate that the majority of students opt out of scientific careers (OECD 2006).

In Spain, the results of a recent survey on the social perception of science carried out by the Spanish Foundation for Science and Technology (FECYT) show the indifference of a wide range of social sectors. Practically 50% of the sample considers that «science is difficult» and "science does not stimulate interest". There is a drastic and progressive reduction in secondary students' choices related to scientific options (Castaño et al., 2006). On the other hand, it is obvious that science teachers play an essential role in the scientific education quality and the improvement of the students' motivation and learning. New strategies and plans for initial and in-service teacher training improvement are necessary (Glynn & Koballa, 2006).

A coursework design for improving motivation and in-service science teachers training

In 2007, a training project of 70 hours was implemented for in-service science teachers and focused on the design of classroom activities for improving motivation towards scientific and technological education (Llopis et al., 2009; García Gregorio et al., 2009). A network between members of the Principe Felipe Museum staff, Valencia, teachers of the Universidad Politécnica de Valencia, teachers of the German School and French School and the Centre for Teachers training (Centro de Formación de Profesores CEFIRE) was created to work for a committed, enjoyable and engaging science. The group constituted a practice community in order to collaborate with science teachers sharing experiments, activities with toys and devices, science in daily life, Science-Technology-Society-Environment (STSE) texts, drawing on didactic experiences of other European countries (Germany, France and the United Kingdom).

Project Objectives

- Sharing an environment for enriching the teachers' motivation in a practice community.
- Communicating science and technological issues, igniting motivation of the teachers and students through a vision of an enjoyable and creative science, committed to sustainable human development and the students' interests
- Generating and applying projects in the classroom, analyzing its impact on the improvement of students' learning.

The principal characteristics in the coursework design are:

a) *Integration of multidisciplinary contents specially in STSE perspectives.*

b) *Applicability to the classroom.* The course includes the elaboration of an individual school Project by the teachers, presenting the outcomes and the results of its implementation with students in a workshop (videos, power point presentations, artifacts and experiment designed, etc.).

c) *Improvement the practice of action research as professional development,* promoting the self-reflection about the teachers own motivation, styles and learning environments.

d) *Multiplicity of actors,* including formal, in-formal and non-formal education agents such as museum staff, teachers, teacher educators and university staff.

e) *Different education culture collaboration,* throughout the meeting between teachers from Spain, France and Germany, with their own didactic background and their own educational experiences.

f) *Active methodologies and multiple didactic strategies.* The coursework is based on constructivist orientation, promoting models as the Inquiry-Based Science Education (IBSE), Project Based Learning (PBL), problem solving and, in general, the *learning by doing or hands-on learning*). In addition, teamwork, creativity and use of Information and Communication Technologies (ICT) are used to promote learning.

e) *Diversification of activities and didactic resources,* combining discipline and inter-discipline perspectives and a wide variety of resources (toys, scientific and technological devices and artifacts, articles, press and magazines, Internet resources, etc.)

Results

The course was implemented for three consecutive years with the application of a set of evaluation indicators (pre and post-questionnaires, a general survey and observation during the course development). Aspects that were considered as important by teachers have been: novelty (98%), applicability to the classroom (98%), links with daily life (97%) and improvement in student motivation (95%). These results re-affirm the consistency in the course design (Llopis et al., 2009). There are more than one hundred projects developed between 2007 and 2009. One of them, called "El Blog: una herramienta de motivación para el estudio de las Ciencias" (The blog: a useful instrument for science study), has been distinguished in 2009 with the 1st National Award by the Ministerio de Educación (**http://cienciaalucinante.blogspot.com**, "amazing science") and Project "Digital pen for the Wii" has been recently distinguished with other award (Premio Manises Innova). Of the elaborated projects, 15% corresponds to technological applications, 44% to problems in daily life and 56% focused on curricular themes. Other project titles include: Love thermometer, *Truffles with Hazelnuts, Eating Cells, Does the laboratory's air fit in a matchbox?, Gummysciences, Genetics of the bitter flavor, The infernal catapult…*

The results show the importance of achieving the creation of multiple actor networks, constituting a new approach to the educational innovation through the generation of a true community of practice. It is also an especially effective tool to stimulate students' interest through science with personal and social relevance, that is simultaneously creative and enjoyable.

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Annex 3. Science teaching by inquiry for primary school

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The student in the primary school, mainly in the area of sciences, does not necessarily learn "scientific" content. There is a need to look for the content within the world the child lives and plays, in such a way that this leads the student to build the first important meaningful understanding of the scientific world, to build new knowledge that can be acquired later, in a more systematized manner closer to the scientific concepts.

The Research Laboratory and Teaching of Physics – LaPEF of the School of Education at the University of São Paulo tried to work with problems from physics, planning experimental activities in which the students could discuss and propose solutions according to their development and their worldview, but in a way that would lead them to scientific knowledge later.

It is not every problem or any phenomena that the children are able to explain. We need to select those phenomena that are on the level of the children so that they, by means of actions and thinking, are aware of what they had done and try to give a coherent explanation – not a magic one -, and can develop the necessary attitudes to the intellectual development which will be basic to the learning of Science. We tried to favor an experimental attitude that encouraged the children to act upon the objects to test their hypotheses and solve the problem proposed.

We organized the activities, wrote a book (Carvalho et al. 1998) and gave many courses of teacher development. We produced 15 videos with the collaboration of teachers that showed how the students solved the problems in experimental physics and how the teachers led the learning of the students in these classes.

In each one of those videos when we focused a particular physics problem, we also tried to raise a pedagogical issue, such as: the construction of hypotheses by the children, the proportional thinking, the construction of moral autonomy, the construction of the oral and written language, etc. These videos can be accessed by the public at **www.lapef.fe.usp.br**

One of the important points in the teachers' development was the awareness by the teachers that during the activities developing physics knowledge, the students underwent phases of action and reflection. Even though these phases are not rigid and they at times overlap, it was important for the teacher to understand the role each one of them has, since the role of the teacher throughout the activities is fundamental, so that students can explain the causes.

Having these goals, we created in the courses environments of teaching and learning so that teachers could analyze each phase in the sequence in which they occur during the classes:

A) The proposal of the problem by the teacher;

B) The time for students to solve the problem experimentally formulating and testing their hypotheses in small groups;

C) The questions by the teacher, now with the whole class, leading the students to recount their actions and to be aware of what they had done, (questions such as: how?);

D) The questions by the teachers to explain the causes (questions such as: why?);

E) The questions by the teacher that lead to the use of concept in the children´s daily life; and

F) The guidance by the teacher to the students to write about and draw the problem solved.

One of the questions that always appeared in these courses was ways to teach of other contents areas than physics. This fact also bothered us. Using the structured and tested approach of our physics work, we organized another group, now with a biologist and two pedagogues to plan the teaching and learning sequence, leading the students to build other scientific concepts (biological, chemical and geological) and whenever possible ended in an environmental problem. Based on the conceptual content, these sequences were structured within inquiry teaching with the goal of promoting the scientific literacy of the students. Let us exemplify with a teaching and learning sequence "Navigation and Environment" proposed by the nine-year-old students.

This sequence starts with an experimental investigation activity in which students are going to discuss the importance of the uniform distribution of mass in a body for flotation (the submarine experiment that can be found in one of the videos of teacher development). The following activity will take the students to biographical research about the history of navigation and the means of ship transportation discussing the different forms of ships' loads such as passenger carriers and cargo carriers. The students are introduced the concept of ballast water as a way to guarantee the stability of the ship's load. Besides the physical aspect of the ballast, we taught the students that the micro-organisms can represent the introduction of the species and other habitats in areas where the cargo carrier throw the ballast water of their tanks.

The next activity in the sequence is the game "Prey and Predator" that has the goal of fostering discussions about food chain. These discussions are based, above all, in evidence that students can find in participating in a game and building a chart with the data obtained. With this chart, it is possible to discuss the dynamics of the populations. The next activity leads to the relation between food chains and the micro-organisms derived from the ballast water thrown by the ships. The sequence ends with the presentation of the Brazilian environmental problem and the infestation of golden mussel that invaded hydro-electric power station at Itaipu (south of Brazil).

This way, it was possible to discuss in the classroom themes which varied from scientific phenomena to technological devices that led to the improvement in society and the way of life, up to environmental issues and questions which were evoked due to the intervention of human beings in nature.

These sequences have already been tested in primary schools and they work as a field of development for research on the teaching of sciences and the learning of students. We already have indications of positive outcomes concerning the indexes of scientific literacy that the students reach, the relationship between the discourses of the students and their writing and how students understand the readings done during the didactic sequences.

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Annex 4. Learning about, for and through lemurs: science and environmental education in Madagascar and the UK through sustainable teacher development.

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Conservation of Madagascar's unique biological heritage is a priority that can be enhanced by education. Education has a crucial role to play in both environmental and social agendas (Dolins et al. 2010). In addition, attitudes of responsibility, sensitivity, empathy towards living things and ethical decision-making can be fostered through the study of ecology and conservation issues in both formal and informal education.

PARTNERSHIP

For this conservation education project Ecole Normale Supérieure (ENS) Antananarivo Madagascar, the University of Winchester and the University of Sussex U.K, as well as a number of non-governmental organisations, worked together in partnership. It involved collaboration between scientists, teacher educators, postgraduate Masters students in both countries, primary school teachers and children, using children's books as a focus for learning in science and the environment. This literature approach is now accepted as shown by the special edition of *Environmental Education Research* 2010.

Dr Alison Jolly produced a series of stories about rare, endemic species unique to Madagascar and places conservation issues in an appropriate ecological setting (Jolly et al. 2007). Each multi-language text focuses on teaching children about the importance of their environments and conserving these, with a view to have a long-term impact on future adult behaviour. The books and related resources such as teachers' notes and posters (to be developed) have the potential to raise similar issues for children in the UK, fostering learning in a global context and application to local issues. The presentation of the two languages Malagasy and English side-by-side in the books should play a useful role in developing a global dimension to the children's learning in both countries (Dupré, Ryan and Cremin 1995).

The partnership drew on the expertise of the different participants to produce teacher support materials and training to use the books as well as devise and carry through evaluations on their use and their adaptation to suit local and cultural need. Our long-term aims are to foster

- Learning that fosters affective and cognitive understanding of the living world; education about, for and through science.
- Learning that contributes to education for sustainable development and citizenship education.
- Whole school learning in a global context.

Members of the project team have held workshops at rural village primary schools in Madagascar. A university tutor worked with Malagasy postgraduate students to plan classroom activities to elicit children's ideas about animals and to engage children in a storybook. The workshops were delivered by the student and the class teachers in a professional collaboration that respected the local classroom expertise of the teachers. Similar workshops have also been held in the UK, with the outcomes monitored by teacher researchers investigating and developing their practice, with university and local authority support.

Outcomes

Early research in Madagascar showed parallels with work elsewhere. A supportive network to undertake action research and professional development has the potential to lead to sustainable capacity building in teacher education and curriculum development. It increases adult and child motivation and enhances learning and teaching through opportunities to reflect on issues of practice. Professionals benefit from opportunities to engage in dialogue about their practice, particularly through appreciative enquiry (Reed 2006). It showed the need for three inter-related aspects of teacher development (Bell 1993):

Professional development - developing teachers' ideas about science education and class practice;
Personal development - attending to and managing feelings associated with the teaching of science;
Social development - helping teachers to work with other teachers in more collaborative and collegial ways so that the teachers' learning will continue beyond the programme.

In the most studied case in Madagascar, 2000 copies of *Ny Aiay Ako* (*Ako the Aye-Aye* a type of lemur unique to Madagascar) supported by the Durrell Wildlife Presentation Trust, were distributed to schools in six regions of the country. Teacher educators in Madagascar developed teacher support materials covering not only environmental education but also possible links across the curriculum such as science and language. The participation of experts with a range of expertise and languages showed the value and challenge of such collaborative activities and the ways that it leads to enrichment of materials and children's learning. A survey of 20 schools in rural areas showed a range of outcomes. Teachers used reading and the radio to find out about environmental education and 70% say they use ecopedagogy as proposed by the WWF. 86% said they found the book very useful and 14% gave no reply. They identified language and knowledge about nature as key outcomes for the pupils. 93% of the children liked the book indicating a range of outcomes. These included a wish to protect animals, a desire to tell the story to others, to wish for further stories like this one, provided new vocabulary and developed their reading. This is in a context where children have access to few books. Capacities such as analysis, synthesis and deduction depend on the teachers making them explicit.

In the UK, teachers investigating their pupils' learning found similar outcomes. It helps primary children develop their understanding of ecosystems, introduces them to other languages, stimulates them to learn more about ecosystems and Madagascar and to develop concerns and intentions to act to protect their own environment. The work also encourages teachers to reflect on and develop their practice, with the potential to improve learning across the curriculum.

The work raises an agenda for future work. We see the value of sharing and respecting the different expertises of the various people involved in the work. We also know that curriculum and classroom change takes time. We are all learning in this new context, scientists, educators, educational researchers, teachers and, most importantly, the children and future citizens.

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Annex 5. A challenge for science literacy: doing science through language.

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To teach science means to open up a new way of seeing the world. This way allows us to identify regularities, make generalizations, and interpret the way nature works. Teaching science also means to promote changes in the initial models of children's thinking, to bring them progressively closer to thinking through theories that make sense of the world.

To achieve this, the children have to understand that the natural world presents a certain internal structure that can be modelled, even though the chosen events and the aspects of the scientific model that explains them have to be adapted to the age and knowledge that are central to each stage of development. To teach science, therefore, is to offer bridges that connect familiar objects and events known by the students to the conceptual entities or models constructed by science to explain them. These science models are powerful and generalisable because they can be applied to new situations where they can be seen to work, and because they are useful in predicting and taking decisions.

Every boy and girl can begin the process of scientific literacy from the first years of school. We have to understand that this means that we offer learning situations that help recover their experience of natural phenomena in order to question themselves about these experiences in order to construct new explanations that have as their reference the models of school science. The classroom thus becomes a space of dialogue and interchange between different ways of seeing, of speaking and of thinking. The participants, students and teachers, bring into play their distinct representations that they have constructed about reality, to contrast them through exploration and direct interaction with objects, materials and living things. In this way, the chosen events are offered as problems, questions or challenges because they oblige the children to think about the way the world works, putting them in the situation of looking for answers and constructing explanations.

We are talking of contexts rich in learning, stimulating and powerful that connect with curiosity and wonder and which favour different ways to access understanding.

Within this framework, the questions and the 'experiments' are equally crucial, along with the discussions of the results and their interpretation and the texts that they produce to communicate and structure their new ideas.

School science and its contribution to literacy.

We start with a wide definition of literacy, which includes basic learning from distinct fields of knowledge, which articulate with one another and are not simply restricted to knowledge of language.

Scientific literacy is today seen as a dynamic combination of attitudes and values, cognitive and manual abilities, concepts, models and ideas about the natural world and the ways to investigate it. This vision includes the construction of a current image of science, of scientific activity, of scientific knowledge and its historical context, which at the same time works for the students. As we all know, from a very early age children construct knowledge about objects, living things and their own body. Further, it is probable that they will meet some science ideas in pre-school even without being able to read or write.

In the primary school, they will carry on this process in a more systematic way with the help of their teacher. For this reason, we have to include science teaching from the beginning of schooling because it makes a specific contribution to the process of becoming literate, both through the **things they think and say** as well as through **the ways to interact with them and to name them**. In this process of learning to see in another way, to articulate 'scientific looking', language plays an irreplaceable role. It allows us to name observed relationships, connecting them with conceptual entities that justify them and favours the emergence of new meanings and new arguments, so converting them into a tool to change their way of thinking about the world.

Here we present an example (adapted from Pujol, 2003) in which a discussion in class is generated through the death of woodlice in the terrarium.

Teacher: What do you think has happened?
Student 1 They didn't have any food to eat…
Teacher: And if we'd put in food wouldn't they have died?
Student 2 For me, they needed water.
Student 3 I think that where we captured them there was moist earth and here in the terrarium it isn't…
Student 4 We'll have to go out into the schoolyard and look more carefully
(They go out again to the schoolyard to observe the woodlice in their habitat.)

In this context, the teacher's question led the students to imagine a hypothetical situation, a change from the initial environmental conditions, which 'made' them think what might have happened in a different scenario and to look for new hypotheses that they had to corroborate. It is an intellectual exercise, which yields scientific meaning to the observations, which they had carried out in the framework of a school 'experiment'. They will need new observations and new actions to find an answer to the proposed hypotheses, but also new questions and new orientations from the teacher.

Doing Science through Language

As we saw in the previous example, the introduction of scientific vocabulary goes along with understanding ideas and concepts that the words represent. Thus, we are far from formal language that is empty of meaning; we are not dealing with memorising definitions but being able to explain ideas.

In this context, modelling scientific phenomena in school implies learning a combination of linguistic modes in order to understand thought and action. For example, **Formulate good questions** is the starting point for looking, seeing and explaining with meaning. **Describe** implies establishing a way of looking at events and includes drawing as a way to amplify the communicative field. **Compare** is to establish events and their relationships. **Justify** is to explain why and because, that is to interpret a set of events based in theory and to use scientific vocabulary in context. Finally, **argumentation** allows the proposal and validation of explanations using theoretical and rhetorical reasoning appropriate for the audience and the purpose.

In what follows, we offer some examples taken from genuine classrooms and elementary school pupils' exercise books, which show the way that children do science at the same time as developing cognitive linguistic competences in context.

For example, when the teacher posed the following, **"Draw what you think is inside a seed"**, the children had the chance to think about this problem and show through drawings and words what were their ideas. The teacher then gave them the chance to open a seed to contrast their representations and to introduce a new question for the children to respond to. **"What did you see?"** This question focuses detailed observation and pupil exploration.

In another case, the teacher offered a situation or a real problem. For example, going out in to the schoolyard, the teacher asked them to draw round their shadows with chalk at two different times of the morning. The teacher then asked, **"How do our shadows change? Why do you think what you do? What do you need to make a shadow?"** In this way, **questions** that the teacher formulates promote the construction of scientific explanations and the use of complex forms of reasoning.

In different exploratory or experimental situations encountered within the context of school science activities, the students **describe** through words and drawings real objects or living things, selecting their properties or characteristics in accordance with their scientific perspective. For example, after observing flowers or fruits they have to pay particular attention to the structures and relative sizes, to the different parts and their positions, and so on. In other cases, **Description** is used to categorise properties, for example, when they complete a table where they have to give the size, the shape, the colour and the texture of a fruit; or where they have to present the results comparing the germination of different seeds, in tables or figures. In other examples, they use description to take into account the time variable to relate the effects of changes in objects or organisms after some action.

The students also learn to **justify** their answers in a test with a statement such as **"A bean is a seed because it can germinate"** or asking them to name three examples 'of not seeds' from the samples they have analysed and explain why they have chosen them. They reply, **"Sea salt, the little stones and the tea leaves, because they don't have any cotyledon."**

Finally, we turn to the explanations that 4th grade children offered their peers from second grade, in a rhetorical form appropriate for their audience, using theoretical reasons, based in school science models that they had explored. **"You have to know that to have a shadow you need light and something that's opaque."**

The examples we have presented show that school science is a way to think about the world, that it corresponds to a way of speaking, of writing and of intervening in the world. And it is here that school science has its points of contact with the science of scientists, both are social constructions though of a different order that respond to specific contexts.

Annex 6. Science Education in the Philippines: Where To?

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Basic education in the Philippines is only 10 years (6+4). Science is formally taught starting Grade 3. The Elementary School Science (ESS) is labelled Science and Health but actually covers three areas: Life Science, Physical Science, and Earth Science. Secondary School Science (SSS) starts with Integrated Science (Y1), then Biology (Y2), Chemistry (Y3), and Physics (Y4).

Student performance in international assessment studies (TIMSS 1995, 1999, 2003) is consistently low. Students at G4 and Y2 performed poorly in three cognitive domains: factual knowledge, conceptual understanding, and reasoning and analysis. The same results are observed in the National Achievement Test given by the Department of Education.

Local studies have identified several reasons to account for this situation: lack of qualified teachers, an overloaded curriculum, lack of quality textbooks and instructional materials, and unavailability of science equipment.

In order for the basic education sector to achieve the desired educational outcomes for all Filipinos, the Basic Education Sector Reform Agenda was introduced in 2005. It focuses on specific policy actions within five key reform thrusts: 1) Get all schools to continuously improve; 2) Enable teachers to further enhance their contribution to learning outcomes; 3) Increase social support to attainment of desired learning outcomes; 4) Improve impact on outcomes from complementary early childhood education, alternative learning systems, and private sector participation; and 5) Change institutional culture of DepED to better support these key reform thrusts. In short, the five key reform thrusts of BESRA are on: schools, teachers, social support to learning, complementary interventions, and DepED's institutional culture.

One of the consequences of BESRA is the current curriculum reform initiated by the Bureau of Secondary Education of the Department of Education based on Understanding by Design espoused by Wiggins and McTighe. This project focuses on enduring understandings and essential questions that have value to all students beyond the classroom even if they drop out of school, instead of covering many topics which are not relevant to students in different communities. It also gives emphasis on identifying performance indicators to help curriculum developers and teachers plan lessons using the six facets of understanding.

In support of BESRA, the University of the Philippines, National Institute for Science and Mathematics Education Development (UP NISMED) proposed and developed a science curriculum framework for basic education organized around three interlocking components namely: inquiry skills, attitudes and content and connections, that envisions the development of a scientifically, technologically, and environmentally literate individuals. The Science Curriculum Framework for Basic Education (SCFBE) has two key features which makes it different from the previous documents and the current curriculum piloted by DepED. Its focus is on the cohesiveness of the three components and its G1-10 approach. This approach provides a picture of the total span of the basic education of students and advocates a developmental and integrated approach to curriculum planning, teaching and learning. Furthermore, it shows how students can progress smoothly through the grade levels and avoids the major disjunctions between stages of school evident in previous approaches (UP NISMED, DOST-SEI, DepED, 2010).

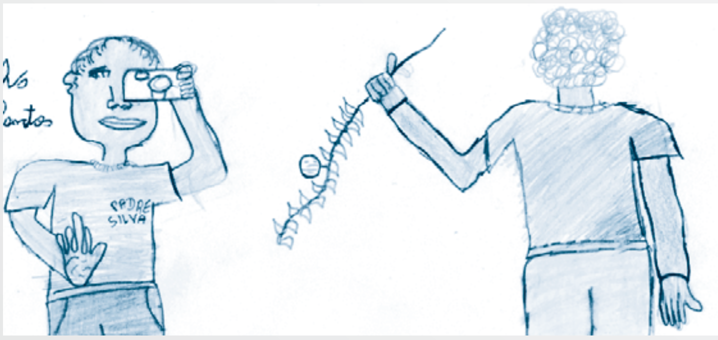
At the teacher education level, the preservice curriculum has been enriched. In 2005, the Commission on Higher Education implemented a new curriculum, two major features of which are the increase in the number of specialization courses to address the lack of qualified teachers and the introduction of Field Study as early as the second year (instead of waiting for students to reach senior year to do their off campus training). Thus, preservice students are exposed to different ways of linking theory and practice. The first batch of graduates under the new curriulum took the licensure examination for teachers (LET) in September, 2009. The results are not so impressive making people infer that perhaps, the implementation of the new curriculum was not standardized. A review of the competencies and description of courses is ongoing.

UP NISMED developed a framework for science teacher education (FSTE) that complements the science framework for basic education. The FSTE includes standards for effective teachers and rubrics to help them plan their own professional growth. In addition, UP NISMED has embarked on a school partnership project called *Collaborative Lesson Research and Development* to help inservice teachers become more competent in their subject matter. The CLRD is an adaptation of the Lesson Study which originated in Japan. It aim is to ultimately improve student learning by enhancing the competence of teachers as they collaboratively plan, implement, and improve lesson guided by a long term goal and sub goals that they formulate. Varied research instruments have been adapted from previous projects managed by UP NISMED, including the Science and Mathematics Manpower Development Program in the 90s which focused on Practical Work Approach in teaching science and mathematics. The PWA approach influences UP NISMED's curriculum and professional development programs and is further guided by its philosophy: Learners learn best most effectively from experiences that are engaging, meaningful, challenging and relevant and from teachers who facilitate construction of knowledge from such experiences. UP NISMED organizes national and international conferences in science and mathematics education on various topics to update and upgrade competence of inservice teachers and teacher educators. The forthcoming conference in October 2010, in on Assessing Learning: Innovations and Practices.

The government of the Philippines has a new leadership. One major innovation being discussed is the lengthening of the basic education cycle to 12 years (K-12) not only to catch on with international standards but also to ensure that students develop maturity and gain enough knowledge and skills to survive in a knowledge-base economy highly influenced by science and technology. This early, debates are going on. Whatever reforms will be approved, the ultimate test will be whether or not the change will result in the development of independent learners, problem solvers, decision makers and productive members of Philippine society.

Annex 7. Botany comes alive

Maria Ângela Pinheiro, Portuguese Teacher in a public school, Campinas and Antonio CR Amorim, Professor of Education, Faculty of Campinas University, São Paulo, Brazil.



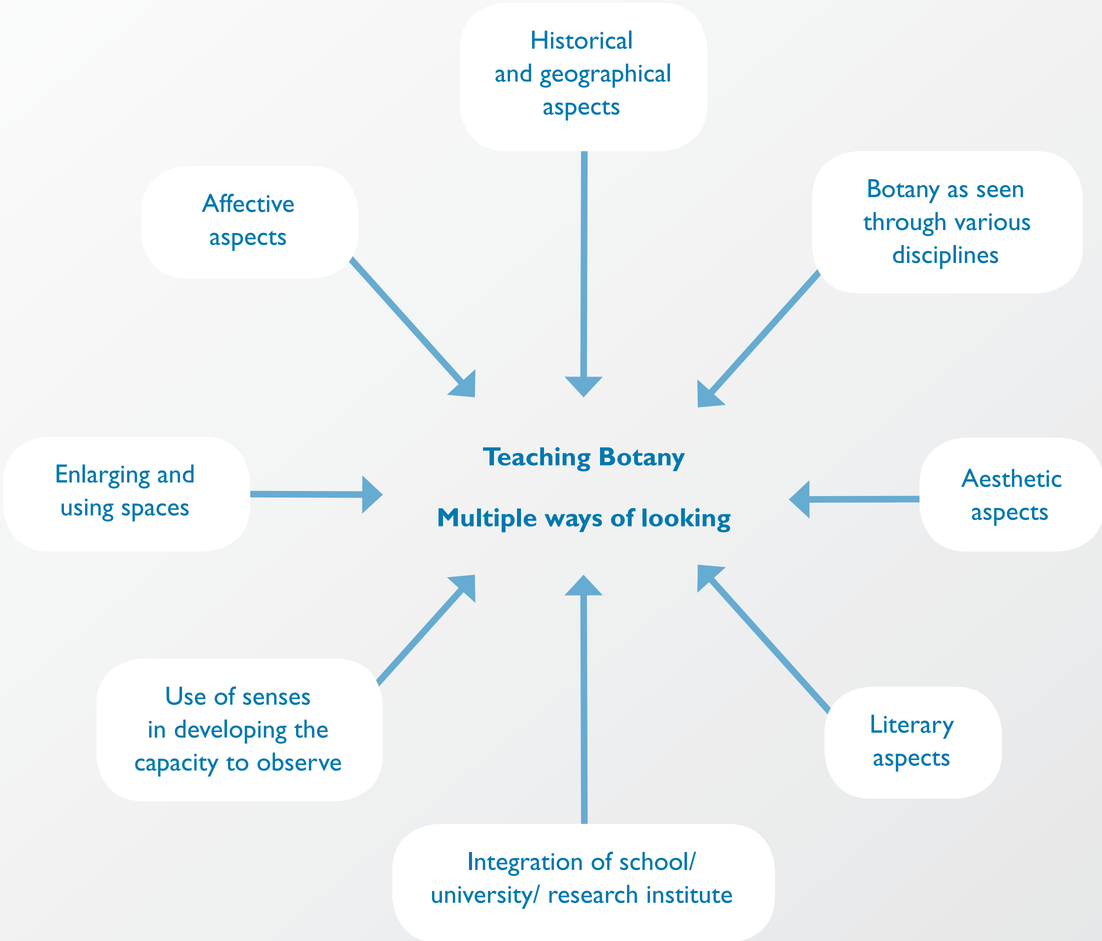
Sometimes teachers complain it is not easy to motivate students to study Botany. This was not what happened with this group of students and teachers, though. They took part in a project called Programa de Ensino do Projeto Flora Fanerogâmica do Estado de São Paulo (FAPESP – 97/02322-0), which took place at "Padre Francisco Silva" school, in Campinas - SP, Brazil, with 6th grade students. It was an interdisciplinary project which incorporated the disciplines of Science, Portuguese, Geography, Arts, Physical Education and History. An integrated project was carried out with professionals from "IAC" (Agronomical Institute in Campinas) and from "Unicamp" (University of Campinas) in the areas of Botany and Education.

Interdisciplinarity, one of the guidelines of the project, was built mainly through collective planning, which was open and flexible. It demanded constant modifications therefore disestablishing disciplines as the organizer of school experiences and knowledge. The group of teachers and researchers had a three-hour meeting once a week where many things were planned and discussed in a collective way: it was an extremely important space for listening, sharing, establishing exchanges and for the union of the group.

> *"… sometimes you are kind of afraid of taking a risk… and alone you can even accommodate, but if you are in a group, sharing a project together, a proposal, it makes you walk with more confidence, with more protection, reciprocity…"*
> (Portuguese Language teacher)

Although Botany was the starting point of the project, while (re)building the school curriculum, different areas of knowledge established intrinsic inter-relations. Each school subject contributed, suggested, criticized, making the experience richer and opening different possibilities of approaching knowledge in a more heterogeneous and chaotic way, less organized and linear.

A network of knowledges was woven:



After all these experiences, the teachers could establish a different relation with school knowledge and with their own school subject.

> *"… the classes which we gave today, the Geography classes, they are not limited only to Geography knowledge, they include literature, history, all the knowledge areas…"* (Geography teacher)

> *"It was interesting to see the P.E. teacher analyzing the small glands of the lemon leaves. Or the Portuguese teacher talking to the students about the kinds of leaves. Botany doesn't belong to Biology anymore; it belongs to all of us."* (Science teacher)

By taking into consideration different meanings and knowledge the curriculum was (re) built and the possibility for the creation of a multiple curriculum emerged.

> *"…it's important to observe nature too, the children experimenting looking at a tree, looking at a plant, observing a flower… the child becomes a better observer…"* **(Art teacher)**

The different ways to encounter curricular (re)construction, which allowed botany to gain another 'life' in school, comes through the process of incorporating research into the practices of teaching. This process helped establish a type of reflexive analysis which we want to stimulate in elementary school teachers that they might experiment, practice.

The outcomes of the research were presented in three groups: *The Web of Interdisciplinarity*; *The Journeys of Pupils as Observers* and *Constructing Botanical Knowledge*.

In summary, we have evidence for intersections between the following specific types of learning:

a) Working in a group brings about an interdisciplinary space, which allows the possibility for personal and professional change. In the professional field, the modifications identified relate principally to the acquisition of research skills and widening of knowledge through conversations across disciplines.

b) Teaching activities, when they are analysed reflexively, represent a further instance of learning research skills and these stand out as a necessary inclusion in the professional work of the teacher. Such analyses support a change that goes beyond the superficial and immediate perceptions of their work and that of their students. They also act as a source for constant replanning.

c) The roles of students and teachers, within the processes of teaching and learning, are reconfigured during the systematisation of the different sorts of data. They learn to see school situations in a less totalising panorama, a view that includes differences and particulars. In this way, foci of movement and change can be perceived, suggested by students and by teachers, which in turn can act as other points of departure as we weave new connections in the search for curricular innovation.

d) The relations between the research work of Unicamp and that of the IAC with the programme of teaching are recognised as participants in curriculum construction, giving meaning to this partnership, another innovation.

To experience research attitudes and relate them to teaching is an initiative that is both scary and stimulating. The teachers did not initially choose questions for research and the questions were not decided given before the start of the project.

During the two year period of working together in school and in general meetings of the project, there developed a process of forming a research group, sensitive to relevant questions and furnishing the necessary instruments to function as researchers in a school context. The objects of research were chosen by the participants in the group to analyse aspects of practice, and to understand and transform them through being a group. This long process of sharing, of change and of involvement was fundamental in enabling us as a group to perceive more precisely current questions appropriate for research. Becoming teacher researchers came about through the group, in which they reflected on the individual and collective processes, and which supported decision-making and any changes thought necessary.

In this way, assuming the role of teacher researcher was not simulated. It was generated throughout a process over a year of working together. The project shows that being a teacher–researcher instigates and is necessary for a more educational practice in schools.

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Annex 8. The child, the clown and the scientist

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Introduction

The concept of a *science clown*, at least as it is used in France, is closely connected to the association *Les Atomes Crochus* (**www.atomes-crochus.org**). Using a range of ways from standard theatre pieces to street theatre, Les *Atomes Crochus* continues to explore and exploit the hidden treasures that come from the synergy of co-construction between scientists and actors. Mediator without equal, with a natural sympathy with and from the audience, the science clown is becoming an essential figure in the landscape of science communication.

The concept of *science clown*

The clown's role is built on improvisation in the moment, the concrete, the specific, the imagined, with those they interact with and with the audience. It is not simply a case of putting on a red nose to become a clown. Quite the contrary, behind this theatrical figure there are rigorous principles of engagement and a myth to be preserved, as the association *Bataclown* illustrates through its charter (**www.bataclown.com**), which relate to the fundamentals of the role of the clown and the rules for their training.

The least we expect is a *science clown* that is above all a good clown, as defined above. But also a clown who creates, for the public and through whatever scenario or form, a rapport with science. A science present through its contents and through its way of working, through its applications, through questioning ethics and society; put simply the role of the science researcher. The relationship with science that is proposed will usually be playful and humorous, a novel viewpoint, sometimes impertinent, legitimated by the closeness of the person of the clown. In this way, through their closeness to their public and by dedramatising science that they show, it becomes easy for the clown to be a true intermediary or mediator for science, as we explain and demonstrate below.

The clown, an excellent science mediator

More than simply the realisation that the clown is a sort of friend to a child, we see the opportunity for the child to identify himself or herself with the clown. 'The most hopeless cases can dream of a world in their own image because at the worst, most perilous moments, the clown succeeds and shows unexpected prowess' (Martin cited by Bonange 2000). So, the lowest attaining pupil can dream of becoming a scientist when they see the clown developing their understanding of natural phenomena. This bumbling innocent who has found himself by chance in the midst of unsettling and strange objects and products, the *science clown* asks questions, makes mistakes, imagines, is told off or encouraged. In short, the clown learns; and shows the children that they can learn too.

If we compare this with the allosteric learning model developed by Giordan and Girault (2005), this process of identification opens more ways to learn. Let us imagine that on a given topic, the most obvious conceptual errors of a given age of children are collected in class from a science clown's intervention, then heard coming from the mouth of the clown in the same way as the children gave them. We can foresee that the clown be taken less seriously so that the children would not hesitate to question the clown's ideas, even though they might be relatively credible as they come from the children's own conceptions.

The *science clown* is not an intellectual. Naïve and totally inhibited, he is a living example of curiosity and inventiveness. In effect, he knows how to pose questions that nobody else does or does not dare to ask, bringing his audience close to science, which they have often seen as inaccessible and is a return to the fundamentals. His limitless imagination, his manual dexterity and the absence of limits allow him to juggle, in all meanings of the word, equally with objects and their properties, with science concepts and with appropriate questions.

Embodied in flesh and blood in the form of this imagined figure, the scientist no longer represents knowledge and authority. Quite the contrary. Released from all social norms connected with the need to respect and obey adults, the person - half adult half child - is particularly suited to the role of mediator between science and the child.

Some reflections

Through their education in drama, the clown artist and the scientist together can construct a *science clown*. This concept is an exemplar of the co-construction through the reciprocal exploration of the respective fields of expertise (Eastes 2009). What pleasure for the scientist to see 'their' experiments and experiences revisited and for the artist to see their repertoire renewed.

Despite the pedagogical possibilities of the *science clown*, in terms of transmission of knowledge there are great risks that the audience might leave with some false ideas that they believe they have seen, heard or understood. In order to overcome or limit these risks, three solutions are offered. The first is to ask the actors to pinpoint all their problematic moments, such as those we have suggested. The second, less ambitious but logistically more expensive, more certain but less elegant is that the clown is accompanied by a scientist who would intervene during the action or at the end of the spectacle. Finally, half way between the other two, the third is to resort to text. For this, we have produced an explanatory leaflet for the topic, which we usually give out to the audience at the end.

Conclusion

Though the social role of the clown is well developed, as shown by their presence where children are ill or when there are social or family problems, it is astonishing to show that such explorations have not reached education, where children might be equally suffering, though there are cases looking at teacher education through clowns (Rousseaux 2000).

When we consider

- the energy that is unleashed,
- the power of the communication,
- the fascination that is aroused,
- the identification that is induced in the young spectators and
- the consequent pedagogical opportunities that follow, both emotional and cognitive, we think it important to share our analysis of this concept, which still appears to us to be a novel way to develop understanding in science.

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Further details

Informations : **www.atomes-crochus.org/spectacles/SpectaclesDeClowns.htm**

Bibliographie : **www.bataclown.com/spip.php?rubrique22**

Extrait vidéo 1 (*Ursule FaBulle*) : **www.cognition.ens.fr/~reeastes/ursule.avi**

Extrait vidéo 2 (*Ursule FaBulle*) : **www.developpementdurablelejournal.fr/spip.php?article526**

Annex 9. A CTC Science Classroom: Unique science education solutions of Brazilian origin,

Arlita McNamee, MES, Educational Projects Consultant, Sangarí Brazil.

A CTC classroom looks different than any other type of science classroom. "What are clouds made of?" is the inquiry-based approach that opens the discussion for a first grade classroom to describe what they know about a new topic. With CTC Book in hand, students divide into groups of two or four, retrieve the *investigative materials* from the CTC cabinet and begin an experiment to test the hypothesis that they have developed about cloud formation. After presenting their findings, teachers help students to complete their understanding of the new concept, and they record their discovery in their science journals, store their materials, and leave class with a special task to develop at home.

Science in basic education

In Brazil today, as in Latin America in general, low ranking on international evaluations, high drop-out numbers and repetition rates are all evidence of the major challenges in improving education quality. The country's future economic growth depends on making some nation-wide changes to education. From petroleum and alternative fuels production to infrastructure development, engineering and construction, it is clear that the economy depends on the scientific literacy of the next generation, and within five years there are likely to be as many as two million new jobs in these areas in Brazil alone (Andad, Esteves and Neto, 2009)

The great challenges faced by educators today include a shortage of adequately trained teachers in the core disciplines, unequal and insufficient distribution of materials and resources, lack of time for planning lessons and evaluations, poorly defined learning objectives and a lack of training in pedagogical approaches that teach scientific literacy and scientific thinking.

In response to extensive research on quality of education, Sangari has worked for over ten years to develop a program that includes professional development for in-service teachers in content and methods, mentoring programs, structured curriculum, and provision of instructional materials, as a means for improving quality of education and specifically in developing teachers' capacity to teach science.

CTC science program

The CTC Science Program, developed by Sangari, was designed to provide all of the circumstances necessary to improve students' achievement in all disciplines through the study of the natural sciences. CTC has been adopted in state and city-wide school districts in Brazil, Argentina and the United States, and has been used by over 500,000 students to date. The truly unique quality of this program is that it combines all of the elements necessary to develop scientific literacy and achieve measurable results in student performance.

The pedagogical approach to CTC Science includes developing skills for analysis, discussion, critical thinking, hypothesizing and decision making, which will penetrate the other subject areas. Several evaluations have indicated that scientific method and inquiry-based methods improve student performance in mathematics and language, in addition to science. Scientific literacy enables students not only to understand the natural world, but as well provides them with the tools to understand the impact of human activity and, engage, participate and adapt to the changes they will face in their lifetimes.

Curriculum and instructional materials

Each of the schools that adopts the CTC Program, today more than 1000, follows a unique curriculum, based on teaching thematic units rather than annual textbooks. Selection and order of thematic units is done by each school district to align the program with the science curriculum of each local board of education that adopts the program. In this way CTC teaches the national or state level curriculum and prepares students to better understand the interdisciplinary nature of the natural sciences.

A CTC Classroom is transformed into a science laboratory for every science lesson. In addition to providing live plants and animals to accompany units on biology, all of the investigative materials necessary for the activities proposed in the CTC Curriculum are delivered to the school prior to beginning each thematic unit. From test tubes, microscopes, chemical solutions, games, and electrical circuits, all of the materials are delivered to the schools and stored in the CTC cabinet ready to be used. CTC also provides teachers with web-based interactive tools and DVDs of film and audio clips, thus preparing teachers to incorporate the multi-media dimension proposed in each unit.

The teachers and students books provided with CTC facilitate teachers' task of planning each lesson, thus maximizing class time and structuring each lesson of the unit to include the opening inquiry, scientific experiment, analysis of results, and conceptual discussion. The structured lessons give teachers and students a clear understanding of learning objectives and achievement standards. Periodic evaluations of student learning provided with the CTC Program give teachers, school administrators, and public sector education departments a clear understanding of student achievement for continuous improvement.

Teacher development

Using an inquiry-based pedagogical approach to teaching the sciences requires an intensive teacher development course in pedagogical methods. Through in-school workshops, peer group settings, and virtual formats, all teachers that work with the curriculum receive an initial training to use the CTC method to emphasize experimentation and practice-based approaches to the sciences. In addition, teachers receive specific content training at the onset of each new thematic unit and have access to a special web portal where all of the books, experiments, training sessions, discussion blogs and other tools are available for teachers to access in their own time.

Once they begin teaching CTC classes, the schools are assigned a tutor, a master-teacher who brings teachers together to discuss any questions about content or approach in addition to helping school administrators to oversee and monitor the program. In this way the program also supports schools to develop collaborative learning opportunities for teachers, to monitor student achievement, to evaluate results and improve continuously.

Impact of CTC program

Schools that use the CTC Science program, in many cases use the resources and technical support to develop additional activities, such as exhibitions and science fairs, to further develop students and teachers understanding of science content. By developing both school resources and teacher education programs CTC provides the opportunity for schools and communities to develop their capacities for teaching science, improving school quality, improving student retention and repetition rates and improving student performance.

As a program that focuses on standardization of learning objectives and the provision of resources at the school level, the greatest impacts of this program are likely to be seen in the lower performing schools and low performing regions. As such, CTC Science is an important part of commitment to both developing human capital for information-based and technological industries as well as in improving economic equality and social inclusion.

References

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30 March – 1 April 2009

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"Access to scientific knowledge for peaceful purposes for a very early age is part of the right to education belonging to all men and women, (...) science education is essential for human development, for creating endogenous scientific capacity and for having active and informed citizens"

"Science education, in the broad sense, without discrimination and encompassing all levels and modalities, is a fundamental prerequisite for democracy and for ensuring sustainable development"

Declaration on Science – World Conference on Science

Budapest 1999