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Three Contributions to Science Education

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Three Contributions to Science Education

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Preface

This publication is a collection of three independent papers, written in different contexts and for different audiences. In this publication, the papers are considerably extended, reworked and updated. The three papers are the following:

Paper I
Science and Technology Education – Current Challenges and Possible Solutions

This paper is based on a document prepared for a meeting among European ministers of science, research and education, held in March 2001 in Uppsala in Sweden. The paper has been extended to be published in UNESCO's series *Innovations in Science and Technology Education*. The paper provides a rather comprehensive overview over current challenges in the policy of science education. It is also an introduction to some of the recent literature in the field.

Paper II
Perspectives (and second thoughts) on Scientific Literacy

This paper is based on a paper presented at an OECD meeting on science and technology education, arranged in Oslo 1998. The paper also emerges from a research project supported by The Research Council of Norway. *Science, Technology and Citizenship.*

Paper III
Gender and science and technology education

This paper is based of an invited paper to the conference *Promoting Public Understanding of Science and Technology in Southern Africa* at the University of Western Cape, South Africa. The close link to African science education is removed, and the paper can be seen as an extension of the two pervious ones.

References

For simplicity and to save space, I have collected the references to all papers at the end of the publication.

The three papers have been written in different contexts and for different audiences (policy makers, science educators etc.). In spite of this, there is inevitably some overlap. I have, however, in the revision of the papers, tried to avoid too much repetition. I have also included some cross-referencing between the papers, using "Paper I" (and II and III) as 'pointers'.

I have made these papers available in one collection, in the hope that they will form a whole, and that they may be of some use, mainly in the education of science teachers and for people interested in the role that science and technology play in society and the education system.

It is my hope that the articles will provoke discussion about current challenges related to the role and purpose of science and technology in education, and to serve as a guide to some of the recent literature and perspectives in the field.

Oslo June 2002 Svein Sjøberg

Contents

(The contents of each paper is placed in the beginning of the paper.)

Paper I

Science and Technology Education Current Challenges and Possible Solutions

To be published in Jenkins, Edgar (ed) (2002) ***Innovations in Science and Technology Education Vol VIII*** **Paris, UNESCO**

Svein Sjøberg[1], University of Oslo

Contents

[1] This chapter is based on an invited contribution to Meeting of Ministers of Education and Research in the European Union held in Uppsala, Sweden 1-3 March 2001

Summary

This chapter describes and analyses some of the challenges facing science and technology (S&T) education by relating these to their wider social setting. Although the focus is on aspects emerging from a European (or OECD) context, some of the issues raised are likely to have a wider validity.

After describing the problematic pattern of student enrolment in science and technology, the chapter suggests a series of underlying reasons for the difficulties that have arisen. The description is necessarily tentative and exploratory, and it is intended to present ideas for a discussion of possible explanations. This is followed by a similar analysis of *who* needs science and technology education, and for what purposes. The point here is that the problem of student recruitment may be perceived differently from different perspectives and by different interests. Hence, there may also be different views on suitable strategies to overcome it. The chapter also offers a critical description of school science and technology education, together with a brief account of some recent international trends. These trends may provide ideas for possible ways forward.

Science and Technology[2]: Key features of modern societies

> *No period in history has been more penetrated by and more dependent on the natural sciences than the twentieth century. Yet no period ... has been less at ease with it. This is the paradox with which the historian of the century must grapple.* (Hobsbawm 1995, p.522)

Our societies are dominated and even 'driven' by ideas and products from science and technology (S&T) and it is very likely that the influence of science and technology on our lives will continue to increase in the years to come. Scientific and technological knowledge, skills and artefacts 'invade' all realms of life in modern society: the workplace and the public sphere are increasingly dependent on new as well as upon more established technologies. So, too, are the private sphere and our leisure time. Scientific and technological knowledge and skills are crucial for most of our actions and decisions, as workers, as voters, as consumers, etc. Meaningful and independent participation in modern democracies assumes an ability to judge the evidence and arguments associated with the many socio-scientific issues that appear on the political agenda.

In short, modern societies need people with scientific and technological qualifications at the highest level as well as a general public which has a broad understanding of the contents and methods of science and technology, coupled with an insight into their role as social forces that shape the future. Science and technology are major cultural products of human history, and all citizens, independently of their occupational 'needs', should be acquainted with them as elements of human culture. While science and technology are obviously important

[2] Science and technology are different, but related as forms of knowledge and as forms of activities. Science is concerned about developing general and universal explanations of reality; technology is concerned about finding workable solutions to practical problems. Technology is *not* the same as applied science, and scientific understanding does not always precede technological developments. In spite of the differences, the acronym S&T will be used in the following.

for economic well-being, they must also seen from the perspective of a broadly based *liberal education* [3].

One might expect the increasing significance of science and technology to be accompanied by a parallel growth in interest in these subjects and in an understanding of basic scientific ideas and ways of thinking. This does, however, not seem to be the case, especially in the more developed countries of Europe and the OECD.

The evidence for such claims is in part based on 'hard facts' (educational statistics relating to subject choice in schools, enrolment in tertiary education etc.), in part on recent large–scale comparative studies like TIMSS and PISA (described later in this chapter) and in part on research into, and analysis of, contemporary social trends. The situation is briefly described and analysed below.

Challenges and perspectives

Falling enrolment, increasing gender gap?

In many countries, recruitment to scientific and technological studies is falling, or at least not developing as fast as expected or planned for. This lack of interest in science often manifests itself at school level at the age where curricular choices are made. In many countries, there is a noticeable decrease in the numbers of students choosing (some of) the sciences. The trend is consolidated in admissions to tertiary education. A similar trend occurs in some areas of engineering and technology studies. It should, however, be noted that there are large (and interesting) differences between the various European countries and between the different disciplines within science and technology. The fall in recruitment has been particularly marked in physics and mathematics.

In many countries, there is also a growing gender gap in the choice of scientific and technological subjects at both school and tertiary level. Many countries have had a long period of steady growth in female participation in traditionally male fields of study, but this positive trend seems now to have been broken in some countries. It is a

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[3] The term 'liberal education' is here used as synonymous with the concept of *Bildung* (used in e.g., German and Swedish), *formation* used in e.g. French, *dannelse* (used in Danish and Norwegian) etc.

paradox that the break is most marked in some of the Nordic countries, where gender equity has been a prime educational aim for decades. For example, while the Nordic countries come out on top of all the countries in the world on the *Gender Empowerment Measure*, an indicator developed by United Nations Development Programme (UNDP 2001), the same countries have very low female participation rates in science- and technology-related occupations and studies.

Concern about unsatisfactory enrolment in science and technology is voiced by many interest groups. Industrial leaders are worried about the recruitment of a qualified work force. Universities and research institutions are anxious about the recruitment of new researchers, and education authorities are worried about the already visible lack of qualified teachers of the scientific and technological subjects. In some countries, the difficulty of recruiting sufficient numbers of new entrants to the teaching profession has become a matter of national concern, especially when the level of recruitment does not even allow for the replacement of those who are retiring. This concern is often based on comprehensive appraisals of the education and labour markets.

The concern is not confined to numbers. There is also a more or less identifiable fall in the *quality* of the newcomers. A lower quality may, of course, be a consequence of the fact that very few candidates compete for places at institutions where the entrance qualifications were previously very high. Many institutions of higher education are unable to fill their places in science and technology with students of a satisfactory quality.

The problems in recruitment are revealed by a range of objective and uncontroversial educational statistics. Cross-national data on a range of issues are now collected and published by UNESCO, the OECD, the European Union and other organisations, and the development of common descriptors and criteria has made its possible to make comparisons between different countries and regions. Evidence about pupils' achievements, quality, interests etc. is available from a number of research projects, notably large comparative surveys such as TIMSS and PISA. Some details are given below in Box 1.

Box 1. Statistical information and large-scale comparative studies
There are many excellent sources of up-to-date international information and analysis on education. Here are a few of them.
UNESCO is the body with a global responsibility in this field. It defines common indicators to facilitate valid international comparisons, and collects the relevant data. These are published in comprehensive published statistical reports that are also available via the web site http://www.unesco.org/

At regular intervals, UNESCO also publishes more analytical, global reports such as *The World Education Report* (UNESCO 2000), together with more targeted and specific reports on progress in the field of education.

The *OECD* has a large education sector, and it publishes an important annual report *Education at a Glance* (i.e. OECD 2001b). These, as well as other reports, including underlying statistical annexes are available online at http://www.oecd.org/ Although the focus is on the OECD countries, the data as well as the research cover other countries.
For science and technology (as well as for mathematics) education, the TIMSS study (Third International Mathematics and Science Study) has become very influential. TIMSS is one of many IEA studies (International Association for the Evaluation of Educational Achievement). Background information as well as downloadable reports and data files are available at http://timss.bc.edu/.

TIMSS will be followed up in years to come (from 2002), although the acronym TIMSS will get a somewhat different meaning (e.g., T for 'Trends' instead of 'Third')

The OECD has recently developed its own set of studies of student achievement, under the acronym of PISA *(Programme for International Student Assessment)*. PISA covers some 30 OECD countries together with some non-OECD countries. It aims at assessing how far students who are approaching the end of compulsory education (about the age of 15) have acquired some of the knowledge and skills that are essential for full participation in society. The first report (OECD 2001a) presents evidence from the first round of data collection on the performance in reading, mathematical and scientific literacy of students, schools and countries. It reveals factors that influence the development of these skills at home and at school, and examines the implications for policy development. Other reports and rounds of data collection will follow, and these studies are likely to have a great political significance in the future. Reports, background material and statistical data are available at http://www.pisa.oecd.org/

Achievement studies – the critique

Large-scale comparative studies such as TIMSS and, to a lesser extent, PISA may have the (possibly unintended) side effect of harmonising or universalising science (and other) curricula across nations. Test format as well as curriculum content may come to provide standards, 'benchmarks' or norms for participating countries as well as for other countries not immediately involved in the research. In fact, the term 'benchmark' is frequently used in TIMSS. An example is the "TIMSS 1999 Benchmarking Study" that sets out to compare states and districts across the Untied States.

Furthermore, the international and cross-cultural nature of studies such as TIMSS has necessarily required the development of test items that can be used independently of educational or social context in an attempt to avoid 'cultural bias'. As a result, these test items tend to become decontextualized and rather abstract. This approach runs contrary to recent thinking about teaching, learning and curriculum development, in which personal and contextual relevance is emerging as a key educational concern. The publication and availability of TIMSS items in many countries might even be said to provide an 'incentive' to use tests that, in both their closed multiple choice format and their lack of social context, run contrary to national or local traditions.

Comparative research in education is important, but there is an obvious need to complement the valuable data from TIMSS-like studies with more open and culturally sensitive information and perspectives (Atkin and Black 1997). The PISA study is an attempt to widen the scope of such large-scale studies, and the underlying framework for PISA is, in contrast to TIMSS, not bound to school curricula. The publication of the first results from PISA (OECD 2001*a*) suggests that the PISA studies will meet some of the criticisms raised against the IEA-based studies like TIMSS. PISA will continue to develop and produce new results for at least a decade.

Nonetheless, TIMSS and PISA do have some common characteristics. They are both high-level initiatives 'from the top' to monitor scholastic *achievement*, and the main results are published as rankings or league tables. The media coverage, assisted by the projects' own reporting, often trivialises the educational enterprise and reduces it to a contest of national prestige. The studies are also, with some exceptions, confined to rich countries in the OECD. In most countries, these studies are initiated and heavily funded by governments and Ministries of education. This reflects the legitimate needs of decision-makers and politicians to obtain comparative data on the scholastic achievement of their pupils and to have some measures of the efficiency and cost-benefits of their national educational systems. In an age of globalisation and economic competition, national authorities are increasingly concerned about how well their own education system compares with that of others. This, of course, assumes that quality can be measured against common standards. Similarly, national authorities have a legitimate need to obtain comparative international data relating to such parameters as unit costs, the effectiveness of teacher training, the significance of class size, and resource deployment.

One may, with considerable exaggeration, characterize projects like TIMSS and PISA as the educational parallel of so-called Big Science or techno-science. The scale and costs of these comparative studies are many factors higher than the kinds of research in which most science educators are involved. The institutions that undertake these studies are often government agencies for research and development, or research institutions from which the government may reasonably expect a degree of loyalty. Such large-scale research projects do not emerge from an independent and critical academic research perspective, and one may use Ziman's concept of 'post-academic science' (Ziman 2000) to characterize them, their loyalties and their implicit values and commitments.

Not unexpectedly, those who pay the bill also influence the 'definition' of what counts as science. Given the strong domination of this work by the USA, it is no surprise that there seem to be no test items that relate to topics such as the theory of evolution, human reproduction, sexual minorities or sexually transmitted diseases. If such a science curriculum is used to define 'benchmarks', it may lead to a narrow conception of relevance, and hence to a *lowering* of standards, rather than, as intended, the opposite.

Scientific and technological illiteracy and the Public Understanding of Science?

Projects like TIMSS and PISA describe the levels of achievement of children of school age. However, there is a comparable political concern about how the general public relates to science. The concern has many dimensions. These include the nature and level of public scientific and technological knowledge, attitudes and interests, and, of course, the degree of public support for scientific and technological research and the community that undertakes it.

Acronyms like PUST (Public Understanding of Science and Technology) have become indicators of growing unease about the situation. Academic journals are devoted to the relevant issues (e.g., *Public Understanding of Science*) and several research institutions study the challenges involved in promoting the public understanding of science. Phrases like 'scientific illiteracy' are also used, more or less fruitfully, to describe the situation. There is a rich literature in the field, and this is marked by the many, and often conflicting, meanings of some of the terms used. This position has been well reviewed and analysed by Jenkins (1997).

In a series of studies dating back to the 1970s, Miller defined and measured scientific literacy in the United States (e.g., Miller 1983), and his approach is evident in research subsequently undertaken in this field in many other countries. See, for example, the influential Eurobarometer studies (e.g., EU 2001).

A key research institute in this field is the International Center for the Advancement of Scientific Literacy (ICASL) in the USA. With support from the National Science Foundation, this regularly undertakes and publishes surveys of public scientific literacy, as well as of public attitudes to science and technology. There is also international participation in some of these surveys. The Center presents itself the following way:

> Not more than 7 percent of Americans qualify as scientifically literate by relatively lenient standards. Recognizing this serious problem, governments in most industrialized nations are making concerted efforts to address the issue of pervasive illiteracy. (From ICASL presentation at the home page http://www.icasl.org/)

Such studies and conclusions are open to several sorts of criticism (Jenkins, 1994, 1997). The questions asked in these studies are often derived directly from academic science so that lay persons are asked to provide answers to questions such as 'How many planets are there around the Sun?' and 'Which is the larger, an atom or an electron?' The studies can also be seen as attempts by the scientific community to promote its own agenda and interests, by lamenting the level of public understanding of science. Further, given the strong domination by the USA among the organisers of large-scale comparative studies, these seldom accommodate cultural or social differences in the context within which the alleged scientific and technological literacy is presumed to be required.

Several researchers have taken a different approach to the public understanding of science, and investigated 'scientific knowledge in action', i.e., the use made of it in real-life situations (see, for example, Irwin and Wynne 1996; Layton *et al.* 1993) Such studies provide a very different understanding of what constitutes 'the problem' and how it might be addressed.

In spite of the criticism indicated here, reports like the bi-annual *Science and Engineering Indicators* (NSB 2000) provide a wealth of information on many aspects of scientific and technological research in society and education. Although these studies are North American, the large volumes (more than 500 pages) include an important comparative perspective. Reports such as the *2000 National Survey of Science and Mathematics Education* (at http://2000survey.horizon-research.com/) also provide valuable data as well as analysis and comparative insights. Based upon almost six thousand participating science and mathematics teachers in schools across the United States, the study was sponsored by the National Science Foundation.

Statistical data and most surveys, however, do not shed much light on the underlying causes of many of the present educational concerns. *Why* have science and technology apparently lost their attraction for many young people, and *what* might be done to remedy this situation? Without some answers to these questions, intervention programmes designed to increase interest in science and technology are unlikely to succeed.

Disenchantment with S&T? 13 possible reasons....

It is not easy to understand what causes the difficulties in recruitment to scientific and technological studies, or the more specific, related problems such as the gender gap. Reasons for the doubt in, and dissatisfaction with, contemporary science and technology have to be sought in the youth culture and in society at large. The decline in recruitment must be understood as a social and political phenomenon found in many, although not all, highly industrialised countries, but very seldom in less developed countries. This means that the current situation can hardly be explained fully by events or reforms in each individual country. It is necessary to look for more general trends that are common to different countries. The following is an attempt to suggest underlying reasons for the present difficulties, from the perspective of a European country. The listing is tentative, and it needs critical scrutiny and modification in each country. The first point refers to schools, the other are related to wider social trends.

1. ***Outdated and irrelevant curricula***

Many studies show that pupils perceive school science as lacking relevance. It is often described as dull, authoritarian, abstract and theoretical. The curriculum is often overcrowded with unfamiliar concepts and laws. It leaves little room for enjoyment, curiosity and a search for personal meaning and significance. It often lacks a cultural, social or historical dimension, and it seldom treats the contemporary issues related to science and technology.

2. ***Science: difficult and unfashionable?***

Scientific knowledge is by its nature abstract and theoretical and it often contradicts 'common sense' (see, e.g., Wolpert 1993). It is also often developed through controlled experiments in artificial and 'unnatural' and idealized laboratory settings. Learning science therefore often requires hard work and considerable intellectual effort, although there is little doubt that school science could, and should, be better tailored to meet the needs and abilities of pupils. Concentration and sustained hard work do not seem to be a dominant feature of contemporary youth culture. In a world where so many 'channels' compete for the attention of young people, subjects such as science and technology are readily perceived as unfashionable.

3. ***A lack of qualified teachers***
Science and technology are often poorly treated in the preparation of teachers of children of primary school age. Moreover, those students who choose to become primary school teachers are often those who did not study, or did not like, science themselves in school. The present decline in recruitment of science teachers in many countries is particularly evident in secondary schools. In part, it can be attributed to a general decline in teachers' status and relative salary, found in a number of countries. The rather low number of students with scientific backgrounds are able to find more tempting and better paid jobs than teaching. In addition, the teaching profession is becoming increasingly female, especially at the primary level (For data, see, e.g., OECD 2001b and UNESCO 2000).

4. ***Anti- and quasi-scientific trends and 'alternatives'***
In many western countries, there is an upsurge of 'alternative' beliefs in the metaphysical, spiritual and supernatural. These movements are often collected under the label of 'New Age', and they comprise a rich variety of world-views, practices and therapies. They include beliefs in UFOs, astrology and several forms of healing. A common denominator is often the rejection of scientific rationality, which is often characterised pejoratively as mechanistic and/or reductionist. Although most 'alternatives' reject science, some, however, base their ideas on misinterpretations of ideas taken from modern science, like the uncertainty principle and other elements of quantum mechanics, the theory of relativity and the more recent chaos theory.

5. ***Postmodernist attacks on science and technology***
These may be seen as the more substantial and academic version of the critique embedded in the 'alternative' movements referred to above. Many postmodernist thinkers reject some of the basic elements of modern science, including its basic epistemological and ontological tenets. In particular, they reject notions like objectivity and rationality. More extreme versions of postmodernism assert that scientific knowl-

edge claims say more about the researcher than about reality, and that all other 'stories' about the world can be accorded the same epistemological status. In this tradition, notions like 'reality' or 'truth' are seldom used without inverted commas!

These postmodernists' attacks on established scientific thinking have been dubbed, somewhat dramatically, the 'Science War'. They have been met with strong counter-attacks from the scientific community. Book with titles such as *The flight from science and reason* (Gross *et al.* 1997), *Higher Superstition* (Gross and Levitt 1998), *A House Built on Sand – Exposing Postmodernists Myths about Science* (Koertge 1998) and *Fashionable Nonsense: Postmodern Intellectuals' Abuse of Science* (Sokal and Bricmont 1998) indicate the tone of the 'conflict'. Although science as knowledge or as an activity *per se* is unlikely to be shattered by these attacks, the 'Science War' creates an atmosphere of hostility and doubt that deserves to be taken seriously

6. ***Stereotypical image of scientists and engineers***

Many research studies reveal that the perceived image of the typical scientist and engineer is stereotypical and problematic. Portrayed in cartoons, nurtured by some sections of the media and serving the plot of many popular films and plays, the image of the 'crazy scientist' is commonplace. Scientists, especially those working in the mathematically demanding, physical sciences, are perceived by pupils as authoritarian and boring, having narrow and closed minds, and somewhat crazy. They are *not* perceived to be kind or helpful and as working to solve the problems of humankind. It is interesting to note, however, that this somewhat negative image of scientists is found only in the developed and rich countries. Young people in developing countries perceive science and technology as the key to progress and development, and the people working in these areas are correspondingly regarded as heroes and helpers. Cross-cultural evidence from drawings and free writing on such issues are presented in Sjøberg (2000, 2002).

7. ***Disagreement among researchers perceived as problematic***

Scientists disagree about and debate many contemporary socio-scientific issues, e.g., the causes of global warming, the effects of radiation, the possible dangers of genetically modified food. Such discussions are part of the normal processes involved in the healthy development of new scientific knowledge and many argue that this open debate, this 'science in the making' is the hallmark of the scientific endeavour (Latour 1987). In recent years, debate about scientific, technological and socio-scientific/technological issues have become the staple of the mass media, rather than, as hitherto, being confined to the professional research journals and academic conferences. Vigorous debate and disagreement in public may, however, confuse and disappoint those whose acquaintance is limited to the certainties of school science, where scientific knowledge is presented, especially in textbooks, as secure and never as controversial or contested.

8. ***Problematic values and ethos of science***

The traditional values of science are meant to safeguard objectivity, neutrality, disinterestedness and rationality. These and other values of science were described by the sociologist Merton (1942) who coined the acronym CUDOS to represent them. (CUDOS: Communalism; Universalism, Disinterestedness, Originality and Scepticism.) They have since come to be seen as the core ethos of science. Taken to the extreme, however, these values may seem to justify an absence of ethical considerations and a lack of empathy with, and concern for, the social implications of science. The search for universal laws and theories may encourage an image of science as abstract and unrelated to, and disconnected from, human needs and concerns. In these circumstances, science comes to be perceived as 'cold', uncaring and lacking a human face.

Ziman (2000) has commented upon on the issue of values and ethics in science. He describes how recent developments in the development of science have put even the traditional academic ethos under stress. He calls this new contemporary science 'post-academic science', and he urges the scientific community to become more ethically involved than ever before (Ziman 1998).

9. ***Dislike of an over ambitious science?***

The achievements of science may call for admiration, but some also prompt also unease, as exemplified in the quotation in the beginning of this article, from the historian Eric Hobsbawm (1995). Many people dislike the image and ambitions of modern biotechnology and have an emotional and irrational fear about scientists who are 'tampering with Nature' or 'Playing God'. They dislike the notion that individual men and women can be seen merely as instruments for the survival of their genes, as suggested by Dawkins in *The Selfish Gene* (Dawkins 1989). They are suspicious of what they read about the mapping of all the human genes through Human Genome Project and they fear the 'progress' relating to cloning and gene manipulation.

Similarly, many people react emotionally when physicists talk about their quest for 'The Final Theory', also called 'The Theory of Everything', or even the search for 'The God Particle' (the title of a book by Nobel laureate Leon Lederman). So while the high ambitions and great achievements of modern science may attract some young people, they are likely to scare others. For some, science is also seen as intruding into areas that are to be considered sacred and the notion that, in principle, science can explain everything is unwelcome. Others like to think of the natural world ('Nature') as sacred and mystical, rather than as explainable, controllable and rational. An avoidance of science may thus in fact be a deliberate choice of values and therefore not something that may be remedied by simply providing more information, especially by the scientists.

10. *The new image: Big Science and techno-science*

Science used to be seen a search for knowledge driven by individual intellectual curiosity, and, historically, scientists have been rightfully described as radicals and revolutionaries who often challenged religious and political authority. Contemporary science is different in a number of fundamental ways. Recent decades have brought a fusion of science and technology into what is called techno-science or 'Big science'. The work of NASA and CERN, and the Human Genome Project are examples. Today's scientists and engineers often work to serve national, industrial or military interests. The historical shift of scientists from being radical, anti-authoritarian rebels to loyal workers on the payroll of industry, the military or the state can be over-drawn but it is real and had been well described by Hobsbawm (1995 pp. 522-557). The earlier image of the scientist as a dissident or rebel has been replaced with a less exotic image of a worker loyally serving those in power and authority. The previously privileged perception of the scientist as neutral defenders of objectivity and truth is increasingly questioned by the media, by many scholars (e.g. Ziman 1996), and by pupils in schools.

11. Scientists and engineers: No longer heroes?

Not very long ago, scientists and engineers were considered heroes. The scientists produced progressive knowledge and fought superstition and ignorance, the engineers developed new technologies and products that improved the quality of life. This image is, however, now the stuff of history, at least in the more developed countries. For many young people in these prosperous, modern societies, the fight for better health and a better material standard is an unknown history of the past. The present generally high standards of living are taken for granted, rather than understood as fundamentally dependent on advances in science and technology. The fruits of science and technology are there for all to buy off the shelf. What attracts the attention of these young people are often the present evils of environmental degradation, pollution or global warming. The triumphs of the past are set aside in the readiness to blame science and technology for many of the serious problems of the present.

12. ***The new role models: Not in science and technology***

We live in an intellectual, cultural and social world that in part is created by the media. Football players, film stars and pop artists receive global publicity and earn fortunes. The lives of journalists and others working in the media seem interesting and challenging. Although few young people enter these careers, the new role models on either side of the camera create new ideals. Young people also know that lawyers and some of those trading in the financial markets earn ten or a hundred times more money than the physicist in the laboratory. They also know that a lack of knowledge of physics or mathematics is unlikely to hinder those who pursue such careers, although a judge in court is often asked to consider evidence based on scientific arguments and/or statistical inferences.

A white-coated, hardworking and not very well paid scientist in a laboratory is thus not a role model for many of today's young people. The social climate, especially in developed countries, is not one which it is easy to convince young people that they should concentrate on learning science at school or beyond.

13. ***A communication gap between scientists and the 'public'?*** The scientific and technological establishment is often confused and annoyed when confronted with criticism, especially when, historically, it has enjoyed prestige and generous finance and experienced few problems in recruitment. Confronted with public distrust and scepticism, the need now is to justify scientific and technological research and development in public forums. The immediate reaction to this new situation is the search for scapegoats, and too often these are found in the schools and in the media.

The fundamental difficulty is often perceived by the scientific and technological establishment as a lack of information. Criticism and scepticism are often seen as derived from 'misunderstandings' and/or a lack of knowledge on the part of the public. In some instances, this may of course be the case, but, more generally, there is a need for a greater degree of self-criticism within the scientific and technological community, allied with an awareness that communication is a two-way process.

At least some of the 13 points above may have some validity as explanations for the current disenchantment with science and technology, although the weight to be attached each will, of course, vary between countries. Also, while it is a relatively straightforward matter to address some of the points, others are more deep-rooted and lie outside the direct influence of political decisions.

Contradictory (and optimistic) trends?

It is evident from the points raised above that the issues surrounding recruitment to science and technology are many and varied. Some of the recent trends are also contradictory. A falling enrolment seems to suggest a decline in interest in science and technology. This, however, is the case only if enrolment in science and technology education is taken as the sole indicator of interest in these fields. Other indicators give other messages.

For instance, young people in many countries are more interested than ever in *using* many kinds of new technology. It is a paradox that the countries that have the most problems with *recruitment* to scientific and technological studies and careers are precisely those with the most widespread *use* of new technologies by young people. Examples include cellular telephones, personal computers and the Internet. There seems to be an eagerness to *use* the new technologies, but a reluctance to *study* the disciplines that underlie them.

Popular science and technology magazines have also retained their popularity in many countries, and television programmes about science, the environment and technology continue to attract large audiences. Furthermore, survey data for the member countries of the EU (often including some other countries), such as the ongoing series of Eurobarometer surveys, do not give support to general claims about falling interest in, and negative attitudes towards, science and technology. Indeed, to the contrary, these studies indicate a high level of public interest in scientific and technological research and a high level of acceptance of such research as a national priority (EU 2001). The Eurobarometer studies also document that doctors, scientists and engineers have high esteem, much above that enjoyed by lawyers, 'businessmen', journalists, and politicians (EU 2001).

Scientific and technological skill and knowledge are acquired and developed in many different contexts, and not simply in formal settings like schools. The media, museums of various kinds, the workplace and even 'everyday life' provide other learning contexts. Most of the impressive skills that young people have in handling personal computers, the Internet, cellular phones and all sorts of electronic devices are acquired in *informal* out-of-school settings. When the Eurobarometer asked members of the public *where* they had acquired their scientific knowledge, television, the press and the radio featured much more prominently than either schools or universities (EU 2001, p.13).

Young people have often developed more advanced skills in information and communication technology than their teachers at school, even though their understanding of the underlying physical principles may be totally lacking. Young people, as well as many who are older, demonstrate an impressive ability to learn and acquire new skills that they deem to be of relevance to their daily life. Educational authorities might learn important lessons from these areas of learning, seeking to support them while avoiding gender, economic, social or other inequalities in access. Likewise, teachers in schools might well utilize the skills and the knowledge of the young in new and inventive ways.

An international concern...

The growing importance, but increasingly problematic, enrolment in, and status of, science and technology in many countries, provides the obvious background to a growing political concern about science and technology education in schools, higher education, media and the public.

In many countries, the situation has attracted political attention at the highest level, and, in some cases, projects and counter-measures are planned or put in operation.

The Swedish *NOT-project* (http://www.hsv.se/NOT/) and the Portuguese *Ciencia Viva* (http://www.ucv.mct.pt/) are examples of large-scale national programmes. Some of these programmes have also initiated research and prompted discussion and other efforts directed at improving understanding of the dimensions of the problem.

Institutes of scientific and technological research, universities and industrial organizations have also established more or less coordinated intervention programmes. Organisations concerned with 'Big science' have also become involved. A prime example is the project *Physics On Stage* (POS http://www.estec.esa.nl/outreach/pos/), organized jointly by CERN (the European Laboratory for Particle Physics), ESA (the European Space Agency) and ESO (the European Southern Observatory). POS, as well as many other such intervention programmes by professional bodies, have seldom undertaken a convincing analysis as to *why* they are facing the problems of falling enrolment. Some of their descriptions of the situation lack empirical evidence, and are more emotional than rational. Many institutions seem to be driven by nothing more than a need to 'do something' about the situation.

From the available studies in the field, it also seems premature to claim that the public understanding of science and technology is *dete-*

riorating, although such claims are often voiced from interests groups on behalf of the scientific and technological establishment. One could, however, argue that the public understanding of science and technology needs to be much *better* than it currently is, given the crucial role they play in contemporary society. General claims about *falling* standards, however, do not seem to be justified.

Who needs Science and Technology – and Why?

The problems surrounding recruitment to scientific and technological subjects can be viewed from several different perspectives. These range from industrial and governmental anxiety about national, economic competitiveness to concerns about empowerment at the grass-roots level to protect and conserve the natural environment. Different conceptions of the recruitment 'crisis' point towards different solutions, and, as indicated below, there is a range of stakeholders, each with a somewhat different argument to present.

Industry needs people with a high level of qualification in science and technology. Modern industry is high-tech, and it is often referred to as a 'knowledge industry'. The need here is for highly qualified scientists and engineers for survival in a competitive global economy. While such survival is also a matter of national economic well-being, young people will *not* base their educational choices on what is good for the nation.

Universities and research institutions have a similar need for researchers (and teachers) to maintain research at a high international level and to train future generations of experts, researchers and teachers.

Industry, universities and other research based organisations thus need to recruit a highly skilled élite. However, the size of that élite may be quite modest, even in a highly industrialised society, and it would be a mistake to have this group principally in mind when reforming science and technology education within schools. A policy based mainly on the needs of this élite could decrease even further the proportion of young people interested in school science and technology interesting, and who wish to continue their studies in these fields.

Schools need large numbers of well-qualified teachers, but many countries face a problem of both quality and quantity in recruiting to the profession. Well-qualified and enthusiastic teachers are the key to any improvement in the teaching of science and technology in schools, not least in laying the foundations for the future development of the knowledge, interests and attitudes of ordinary citizens once they have left school. Science and technology teachers are also influential in recruiting people to the science and technological sectors of employment.

The long-term effects of a shortage of good science and technology teachers can be very damaging, although they may not be so immediately evident as a comparable shortage in industry and research. Teachers of science or technology need a broad education: - a solid foundation in the relevant academic discipline(s) is important, but it is not enough. They need broader perspectives and skills in order to cope with the kinds of challenges set out earlier in this chapter. In particular, they need not only a foundation in the scientific or technological disciplines, but also an understanding that places these disciplines in their historical and social contexts. Achieving this is likely to require significant reforms in teacher training.

A modern labour market requires people with qualifications in science and technology. This need is great and growing fast, as knowledge and skills based on science and technology become prerequisites for employment in new or emerging sectors of the labour market. It is not only doctors, pharmacists, engineers and technicians who need a scientific or technological education. For example, health workers handle complicated and dangerous equipment and secretaries and office staff need good computer literacy. Likewise, lawyers and juries in court trials have to understand and critically judge evidence and statistical arguments in which knowledge of science and considerations of probability and chance play an increasing role.

New, as well as more traditional, technologies often dominate the workplace, and those with skills in these areas may have a competitive advantage in securing employment or promotion. Many countries have also identified a need for people with scientific or technological skills to replace those retiring in the near future. Beyond this, the general need is for a workforce that is flexible, willing to learn new skills, and able to respond positively to ongoing change. A good grounding in science, technology and mathematics is important here since many innovations are likely to be derived from scientific and technological research and development.

Science and technology education are required for participation as a citizen in a democracy. Modern society is dominated by science and technology, and citizens, acting as consumers and voters, are confronted with a range of science- and technology-related issues. As consumers, we have to take decisions about food and health, the quality and characteristics of products, the claims made in advertisements, etc. As voters, we have to take a stand and be able to judge arguments related to a wide variety of issues. Many of these political issues also have a scientific and/or technological dimension. In such cases, a knowledge of the relevant science or technology has to be combined with values and political ideals. Issues relating to the environment are obviously of this nature, but so, too, are issues relating to a wide range of other matters, including energy, traffic and health policy. It is important that social and political issues should not be seen as 'technical', and thus be left in the hands of 'experts'. A broad public understanding of science and technology is an important democratic safeguard against 'scientism' and the domination of experts.

The above 'democratic argument' for scientific and technological education assumes that people have some understanding both of scientific and technological concepts and principles and of the *nature* of science and technology and the role they play in society. Among much else, people need to know that scientific knowledge is based on argumentation and evidence, and that statistical considerations about risks play an important role in establishing conclusions. In short, while everyone cannot become an expert, everyone should have the intellectual tools to be able to judge which expert, and what kind of arguments, one should trust.

A note of caution, however, is appropriate. Addressing the problem of recruiting of potential Nobel Prize winners and researchers to work at CERN or elsewhere may require quite a different educational strategy from that needed to promote a broad public understanding of science or the protection of wildlife and other natural resources. If so, the challenge is to combine these different concerns and strategies within a flexible education system that also accommodates the notion of life-long learning. The following questions indicate some of the choices that have to be made.

- Should one favour early specialisation, identification and recruitment of the more able?
- To what extent and to what age should one have a comprehensive system for all – or choose streaming and selection?
- Should one maximize individual freedom for pupils to choose according to interests and abilities – or should one postpone choices and hold on to a core curriculum of important contents to be covered by all?
- How should one support 'life long education' and develop adult education and on-the-job-training?

Science and technology in schools – the critique

Science curricula are key factors in developing and sustaining pupils' interest in science. There seems to be a broad agreement about the shortcomings of traditional curricula that still prevail in most countries.

The implicit image of science conveyed by these curricula is that it is mainly a massive body of authoritative and unquestionable knowledge. Most curricula and textbooks are overloaded with facts and information at the expense of concentration on a few 'big ideas' and key principles. There seems to be an attempt to cover most, if not all, parts of established academic science, without any justification for teaching this material in schools that cater for the whole age cohort. Many new words and 'exotic' concepts are introduced on every page of most textbooks. Although very few pupils will pursue further studies in science, preparation for such studies seems to be a guiding curriculum principle. There is often repetition, with the same concepts and laws presented year after year. Such curricula and textbooks often lead to rote learning without any deeper understanding so that, unsurprisingly, many pupils become bored and develop a lasting aversion to science.

Moreover, this textbook science is often criticized for its lack of *relevance* and deeper *meaning* for the learners and their daily life. The content is frequently presented without being related to social and human needs, either present or past, and the historical context of discoveries is reduced to biographical anecdotes. Moreover, the implicit philosophy of textbook science is considered by most scholars to be a simplistic and outdated form of empiricism.

It should also be noted (as in point 2 in the previous listing) that science is often seen by students as demanding and difficult. Scientific ideas are not always easy to grasp, and their understanding sometimes requires concentration and hard work over a long period of time. Many young people today in technologically advanced countries do not readily make the commitment necessary to learn science. If they are to make that commitment, pupils will need to be strongly motivated and sense that they are learning something worthwhile, interesting and valuable to them. This does not often seem to be the case. Although science *per se* can be seen as difficult, the demands of school science can, of course, be adopted to suit the age of the learners.

When pupils have a choice, the science curriculum has to compete for popularity and attention with other school subjects. Many of these subjects have qualities that meet the students' needs for meaning and relevance. The content of such subjects is less authoritarian, and it is easier to accommodate the opinions and feelings of the learners. This is seldom the case in school science as it is presently taught. The situation was well captured in a headline in the *Financial Times* some years ago:- 'Science attracts fewer candidates. Students switch to newer subjects thought to be *more interesting and less demanding*' (15th August 1996).

If scientific and technological education are to meet the needs of the learner and be seen as relevant and meaningful, it is important to know what the learners themselves find interesting and challenging. A number of research projects have tried to map these interests and challenges. Box 2 below contains a brief description of one such project, entitled Science and Scientists (SAS) which explores various aspects of relevance in the teaching and learning of science and technology.

Box 2 The priorities of the learners?

The SAS-study (Science And Scientists) explores various aspects of relevance to the teaching and learning of S&T Some 40 researchers from 21 countries have collected data from about 10 000 pupils at the age of 13. The countries are, in alphabetical order: Australia, Chile, England, Ghana, Hungary, Iceland, India, Japan, Korea, Lesotho, Mozambique, Nigeria, Norway, Papua New Guinea, Philippines, Russia, Spain, Sudan, Sweden, Trinidad, Uganda and USA.

The purpose of the study is to provide an empirical input to debates over priorities in the school curriculum as well as the pedagogies that are likely to appeal to the learners. The SAS-study is presented elsewhere (e.g. Sjøberg 2000 and 2002), but here are some of results that relate to *interesting topics* in the science curriculum. (One of the 7 items in the SAS-study). The questionnaire contains an inventory of 60 possible topics for inclusion in the S&T curriculum, and the children simply mark the ones they would like to learn more about.

Children in developing countries are interested in learning about nearly everything! This is possibly a reflection of the fact that for them, education is a luxury and a privilege, and not seen as a painful duty, as is often the case in more wealthy nations!

Some of the results are hardly surprising; they actually fit well with what one stereotypically calls girls' and boys' interests. The surprise is, however, that the actual difference is so extreme. Take learning about "The car and how it works" as an example. In Norway, 76 % of the boys and 33 % of the girls are interested. Japan is even more extreme, although the actual numbers are much smaller: 36 % of the boys, and only 6 % of the girls are interested! The results for the car-producing Sweden may cause some concern: 83 % of the boys and only 32 % of the girls want to learn about the car. No country has such a large difference between girls and boys on this particular item. In spite of the great gender disparities, some topics seem to be high on the list for girls as well as boys in most countries. Here is an indication:
Most popular among girls and boys in most countries are the following topics:

- The possibility of life outside earth
- Computers, PC, and what we can do with them
- Dinosaurs and why they died out
- Earthquakes and volcanoes
- Music, instruments and sounds
- The moon, the sun and the planets

Similarly, one can identify a list of *the least popular (for girls and boys)* in most (mainly the rich) countries:

- How to improve the harvest in gardens and farms
- How plants grow and what they need
- Plants and animals in my neighbourhood,
- Detergents, soap and how they work
- Food processing, conservation and storage
- Famous scientists and their lives

From this list we see that the concern to make S&T more relevant by concentrating on what is "concrete, near and familiar" is not necessarily meeting the interests of the children. They may, in fact, be more interested in learning about the possibility of life in the universe, extinct dinosaurs, planets, earthquakes and volcanoes!

One important result of the SAS-study is that to build on the interests and experiences of the learner, it may be necessary to abandon the notion of a common, more or less universal, science curriculum, in favour of curricula and teaching materials that are more context-bound and take into account both gender and cultural diversity.

Plans for a more systematic follow-up study to the SAS-project have been developed under the acronym of *ROSE: The Relevance Of Science Education*. (The T for Technology does not appear in the acronym, but will be a key concern.) The target population will be 15 year old pupils, i.e. those towards the end of the compulsory school in many countries, and before streaming usually takes place. (A description of the project is given at http://folk.uio.no/sveinsj/) Researchers and research institutions in more than thirty countries have expressed their interest in participating in this project.

Science and Technology in schools – trends and responses

The challenges facing science and technology education outlined above have been met in different ways. Many countries have introduced more or less radical reforms, and there has been support for curriculum development and experiment. The reforms have been directed at both the content and framing of the *curriculum* and at *pedagogy,* i.e., at teaching methods and the organisation of the learning processes.

There seems to be something of general weakening of the traditional academic influence on the organisation of the school curriculum and it content. An underlying concern, when 'everyone' attends school for 12-13 years, is that science and technology should contribute to the more general aims of schooling. The tendency, therefore, is to gradually redefine what counts as valid school science by broadening the perspective to give attention to some of the social and ethical aspects of science and technology. Some of the trends are discussed briefly below. Although listed separately, many are related and not all are found in all countries, but, collectively, they paint a picture of discernible change.

A. ***Towards 'Science for all'***

More emphasis is being given to those aspects of science that can be seen as contributing to the overall goals of schooling. The key notion is that of liberal education (*allmenn dannelse*, *allmänn Bildning, Bildung, Formation,* etc). Less importance is attached to the traditional academic content of school science and to school science as a preparation for more advanced studies. Specialisation is postponed to the last few years of schooling.

B. ***Towards more subject integration***

In the early years of schooling, science and technology are often more or less integrated with other school subjects. Only later are the sciences presented as separate disciplines. The level at which this specialisation begins varies between countries. In general, the separate science subjects are taught only at the later stages of schooling. In

Norway, for example, this occurs only in the two last years of the upper secondary school.

C. ***Widening perspectives***
More attention is being given to the cultural, historical and philosophical aspects of science and technology in an attempt to portray these as human activities. This increased attention may enhance the appeal of these subjects to those pupils who are searching for some 'meaning' to their studies, rather than the acquisition of factual information and established, orthodox explanations of natural phenomena.

D. ***NOS: The Nature of Science***
The 'nature of science' has become an important concern in the curriculum. This often means a rejection of the stereotypical and false image of science as a simple search for objective and final truths based on unproblematic observations. The recent emphasis on understanding of the nature of science is inevitably related to the attempt to give more attention to its social, cultural and human aspects. Science is now to be presented as knowledge that is built on evidence as well upon arguments deployed in a creative search for meaning and explanation.

E. ***Context becomes important***
Increasing attention is being given to presenting science and technology in contexts that have meaning and relevance for the learner. Themes or topics that illustrate scientific or technological principles are drawn from everyday life or current socio-scientific issues. These themes or topics are often by their nature interdisciplinary, and teaching them requires collaboration between teachers with expertise in different disciplines. In many cases, a project approach to learning is appropriate, although many teachers require to be trained to work in this way.

F. ***Concern for the environment***
Environmental questions are increasingly forming part of school science and technology curricula. In the new Norwegian curriculum, for example, this is even reflected in the name of the relevant subject

which is called 'Science and Environmental Study'. Environmental concerns often embrace socio-scientific issues, the treatment of which also frequently requires project work undertaken in an interdisciplinary setting.

G. *An Emphasis on Technology*

Technology has recently been introduced in many countries as a subject in its own right or as an integral component of general education (as in Sweden). In other countries, it has received found accommodation within the science curriculum, although not simply as a source of interesting examples invoked to illustrate scientific theories or principles. In Denmark, for example, the name of the relevant new subject is 'Nature and technology'.

As a curriculum component, however, 'technology' is often confusing and incoherent. In some countries, technology is placed in the context of 'design and technology' (as in England and Wales). In other countries, the term technology implies modern information technology and ICT. Moreover, in some places the stress is on the technical (and underlying scientific) aspects of technology while, in others, emphasis is placed on the interactions of science, technology and society.

Attention to technology, utility and practical examples is often used to build confidence in the children since, through technology, they can come to understand that science and technology are not just about *knowing* but also about *doing* and *making things work.*

H. *STS:- Science, Technology and Society*

STS has become an acronym for a whole international 'movement' within science and technology education (see, e.g., Solomon and Aikenhead, 1994). The key concern is not only scientific and technological content, but also the relationships between science, technology and society. The trends described above, notably the relevance of context, increased attention to environmental concerns and the role of technology, are fundamental to the STS approach.

I. *Attention to ethics*

When scientific and technological issues are treated in a wider context, it becomes evident that many of the topics have ethical dimensions. This is most obviously the case when dealing with socio-scientific issues, but ethical questions are also involved in discussions relating to so-called 'pure' science, e.g., what sorts of research ought to be prioritised (or even allowed) and how far is it legitimate to use animals in research? Attention to ethical issues may give science and technology a more human 'face' and it is also likely to empower future voters with respect to important political issues on which they are invited to take a stand.

J. ***Less is more***

'Less is more' has become a slogan for curriculum development in a number of countries. More attention is given to the 'great stories' of science and technology and to presentation of key ideas and their development, often in an historical and social context. These key ideas replace (the impossible) attempt to present pupils with an encyclopaedic coverage of the whole of science. By adopting this so-called narrative approach, it is hoped to convey an understanding of the nature of science and technology, to nourish pupils' curiosity about, and respect for, work in these fields, and to avoid the curse of an overcrowded curriculum that currently leaves so little time for reflection and the search for meaning.

K. ***Information technologies as subject matter and as tools***

Information and communication technologies (ICT) are products that are clearly associated with science and technology, not least because the 'hardware' consists of science-based technologies and the 'software' relies upon basic mathematics. As a result, the underlying physical and technical ideas are to an increasing extent treated as important and distinct components of school science and technology curricula. However, ICT also provides new tools that can be used in teaching science and technology. The whole range of conventional software is used, including databases, spreadsheets, statistical and graphical programs. In addition, modelling, visualization and the simulation of processes are important. ICT is also used for taking time series of measurements of a wide variety of parameters ('data logging'). Science and technology are likely to be key elements of strategies to develop ICT as a resource for promoting teaching and learning. It is also likely that science and technology teachers are better equipped, by virtue of their training, for this task than many of their colleagues, although they, too, are likely to need to have their skills brought up-to-date by means of suitable training programmes.

Ways forward?

The preceding paragraphs make clear that the challenges facing contemporary science and technology education are multi-faceted. In addition, those challenges, and the strategies for overcoming them, are perceived differently by the different groups with a legitimate interest in science and technology education. The perspectives of industrial leaders are often different from those of environmental activists. It has also been argued in this chapter that the problems related to interest in, and attitudes towards, science and technology cannot be regarded as solely educational but need to be understood and addressed in a wider social, cultural and political context. As a consequence, the range of possible 'solutions' may be as large and diverse as the ways in which the problem is framed.

Despite this, it is possible to recognise some degree of broad agreement about the reforms that need to be undertaken. Agreement can be reached, for example, about the need to stimulate and maintain young children's curiosity about natural phenomena and how things work. There can also be agreement that *everybody* would benefit from a broad knowledge of key ideas and basic principles in science and technology and an understanding and appreciation of the key roles played by science and technology in contemporary society. Knowledge and appreciation of scientific theories and ideas as major cultural products of humankind also probably also constitute an uncontroversial curriculum goal. This list could be continued, but these examples indicate that it should be possible for different groups to work together to achieve what is often called 'scientific and technological literacy'.

Other issues are necessarily more controversial. How critical a stance should science and technology education adopt towards the involvement of science and technology with the authority of the state, with 'sensitive' military or industrial research, or with political activism? How far should one should permit, or even stimulate, early selection and specialization in order to identify and recruit talented students for advanced scientific and technological studies? It is the difficult task of educational and political authorities to balance often contradictory concerns, and, of course, to stimulate public debate about them.

Finally, if it is accepted that the problems of recruitment to, and attitudes toward, science and technology are deeply embedded in a wider social context, then those problems cannot be solved simply by reforming schools, teacher training institutions, universities or their curricula. Precisely because they are so deeply embedded, they are not amenable to easy one-off solutions. The need is for reforms that are context specific, embrace multiple approaches and are implemented over long periods of time. Initiatives will also have to be monitored, and their development and outcomes subjected to on-going evaluation that is informed by evidence and careful analysis.

References

(Placed at the end of this publication)

Paper II

Perspectives (and second thoughts) on Scientific Literacy

Svein Sjøberg

Contents

Abstract

In this paper, I will present some perspectives on science education as they emerge from recent development in the research literature[1]. I will organise the presentation around the basic questions in science education research (or "fag-didaktikk" in general), the questions of **Why, What and How**? Based on experience from studies of the learning of science (the **How**-question), I will argue that consideration of this question also has forced us to consider seriously some of our aims behind teaching science to all pupils. This will lead me to a critical examination of some of the issues we are facing when trying to promote what we all believe in: *Scientific literacy* for all pupils – or, if we like: *Public understanding of science*. I will try to describe three different dimensions of these concepts.

I will critically review the reasons that we put forward when we argue that everybody should learn science, and argue that young people may have sound reasons for rejecting science, and that we should rethink some of the aims and aspirations we have for science education in a compulsory school.

[1] This paper is a revised and extended version of an invited contribution to an OECD-Seminar on science education in Oslo May 1997. The discussions here have emerged from a research project "Science, Technology and Citizenship", supported by the Research Council of Norway. Two books have been published, based on an international seminar, one in English (Sjøberg and Kallerud (Ed) 1997a), the other in Norwegian (Sjøberg and Kallerud 1997b). The project resulted in three PhDs: Knain 1999, Kolstøe 2001 and Ødegaard 2001.

Introduction

Scientists and science educators often put forward a series of good arguments to support our view that science is good for everybody. Very simplified, the arguments may be grouped like this:

Arguments for the importance of Public Understanding of Science, and 'Science for All':

1. **The *economic* argument:**
   Science as a key preparation for work, and with importance for the individual as well as for the development of society

2. **The *utilitarian* or practical argument:**
   Scientific knowledge as essential for mastery of daily life in a society permeated with science and science-based technology

3. **Science for *citizenship;***
   Science as a qualification for democratic participation in a society where political challenges are strongly related to S&T.

4. **Science for *cultural literacy,***
   Science is seen a major human, cultural product, with knowledge and methods that are cornerstones in a modern world-view and our society.

These are arguments we often take for granted. Our only problem is that young people do *not* see the world like this; young people make different choices, prefer other fields of interests. Our first reaction is, of course, that they do not understand their own interests; our first reaction is that they are ignorant. From this perspective, our task is to inform them better, to make them understand their own good and to rectify what we perceive as misunderstandings and deficits in their knowledge.

We will return to these 4 arguments towards the end of this paper, and it will become clear that I am not convinced about their validity. Let us, however, start by a brief discussion of what might be seen as a problematic background for our present concerns about the status of science education. (These trends are also described briefly in paper I)

Science in Schools: Falling enrolment, increasing gender gap?

If we consider the situation for school science and mathematics in many western or OECD-countries, we seem to have some common trends:

A lack of interest from the pupils, reflected in *falling enrolment*, decreased interest and motivation in schools, and enrolment problems also in higher science-based education, like engineering. In Norway, the number of pupils taking physics to high level in upper secondary level has decreased some 30 % only in the last 4-5 years. Similar numbers are reported from the UK, from Australia and a host of other countries. Institutions for training of engineers in Norway face the possibility of being closed down, and the total number of tertiary students in science is declining year by year. (Also at the time of writing, in 2002). There are, however, interesting variations between different disciplines (and between countries!)

In many countries we also witness an *increasing gender gap*: Biology becoming (even more than before) a girls' subject (in Norway, about 75% of pupils choosing biology are girls), while physics, mathematics (and information technology) are very much the domain of boys (In Norway, some 80% of pupils choosing physics are boys).

This development is very discouraging if gender equity is a concern. After a period of steady growth in the percentage of girls in 'hard' science and technology, we are now experiencing a backlash, at least in the Nordic countries. The issue of gender is treated in more detail in Paper III.

Hostility and anti-science?

Not only is there a lack of popularity of science in schools, we also witness what may be perceived as anti-scientific (and anti-technological) sentiments and movements. Scientific communities are concerned with what they envisage as a growing Scientific illiteracy, and magazines like *Scientific American* make editorials on "Science versus Anti-Science" (January 1997). Our era has been given many names, and we may rightfully ask: In what era do we live; In The Age of Information – or in The Age of Aquarius? A recent issue of prestigious *World Science Report* has the following title of the editorial essay: "The case for scientific literacy" (UNESCO 1996), and the same concern permeates several other initiatives in recent years.

These concerns are serious, and they address trends that are real, trends that should not be ignored. Neither does it help to ridicule or moralise the anti-science camp. In fact, the so-called 'anti-science' camp is not *one* camp, but a complicated set of diverse interests group pushing very different agendas, ranging from environmental activists well versed in science to sects of occult nature way outside the access of rational debate.

Simple explanations claiming to describe all such groups and movements are bound to be misleading and simplistic. Similarly, 'local' explanations, referring to national conditions like school reforms or acts by a minister of education are probably equally unjust. Although tempting for some, we cannot put the blame on influential individuals in key political position. (Like a Danish Bertil Haarder, a Norwegian Gudmund Hernes, a British Margaret Thatcher etc. etc.). These trends transcend national borders. They occur in most hi-tech OECD societies, and explanations must dig deeper.

Let me, therefore, not try to give an explanation, but only point to some elements that might be analysed. Science and technology have been considered the heroes of this century, providing mankind with new insights and new and amazing products. Science and science-based technology has transformed our lives in a way that has been unthinkable for previous generations. (At least for some parts of the world!) But – the arrogance of power has started to show its fruits. It has been said that Science lost its innocence in Hiroshima. Since then, new names and new events have been added.

Names and examples are too familiar: We have come to know names like Seveso, Bhopal, Chernobyl, Exxon Valdez, Brent Spar and products like Orange green and napalm. We know that science has provided good medicines and cures, – but also thalidomide. Issues like environmental pollution and degradation, global warming, depletion of the ozone layer etc. have become symbols of the fruits of development led by S&T. We, scientists and science educators, of course 'know' that it is unfair and incorrect to blame this on S&T *per se*, but the fact is that for many people, science has lost its credibility and technology does not live up to its promises. The fruits of development are not as sweet as promised.

Many people also react towards the public image of science: The S&T community is perceived as arrogant; and too often they simply ignore or ridicule the critique. Many people see the S&T establishment as allied with political and military power and international capital. Whereas S&T once was seen as radical, progressive, critical and heretical, challenging accepted views and the established power, its role has shifted, its loyalty is perceived to sit where the money and the power resides. Therefore, many politically concerned young people reject science; in fact they see Science, Technology and their allies big Industry and Military as an oppressive alliance against most people in the world, and not as a liberating force. In many educational institutions, like teacher training colleges, it has been seen as 'politically progressive' to avoid studies in science. This view is even reflected into elementary science textbooks and in textbooks used in teacher training institutions. (See the later paragraph on S&T in Norwegian elementary school!) "Science bashing" is nearly a cult in parts of social science.

Another dimension is that the internal development of both S and T has made both the knowledge and the products inaccessible.

The knowledge base in contemporary science is too complicated to be understood by lay people, and the products of Technology are too difficult to comprehend and to repair. S&T is not accessible, not understandable, people feel alienated.

The arrogance of science and its proponents are obvious. As a result, many people, in schools and elsewhere, see science nearly as intellectual rape and a kind of intellectual imperialism: Science does often not see its own limitations, science is by many seen as having the ambition to explain more and more. Not only religious fundamentalists react against the pervasive secular ambitions of science to explain and reduce all aspects of life to physiochemical interactions and processes. When lay people are concerned with implications of genetic research and gene manipulation – the response from science is often that people are misinformed and ignorant. Be this right or wrong – this is definitely *not* the way to meet the fact that most people are actually very concerned about what developments in S&T can do to our future. Many people perceive S&T to have the ambition to invade everything, their privacy, their genes, 'playing God'. The reactions from the S&T establishment are not always suited to meet these new challenges.

From such considerations one may conclude that protest and hostility against the S&T establishment is not necessarily a result of anti-scientific attitudes. For many, the critique is meant as a defence for human dignity against a reductionist attempt to eliminate belief, religion, mystique, feelings and emotions. People do not *want* everything to be explained or controlled. And they would definitely not let the scientists play that role – the scientists have lost their credibility as wise rulers. Hence – a return to mysticism may be seen a sound reaction against perceived (and sometimes very real) threats. The points raised here indicate that we are facing some serious problems, often not addressed by science education research. (These points are also discussed in Paper I)

Let us now take a step back and make a short historical review of development in research in science education. In most European languages we use the label 'didaktikk' (Didaktik in German, didactique in French etc.) for our field, and more particular 'fagdidaktikk', when we have a particular field of knowledge in mind (like science).

Unfortunately, the word 'didactic' does not translate well into English, as can be seen from dictionaries:

> **Didactic**
> 1. with message: containing a political or moral message
> 2. fond of instructing or advising others: tending to give instruction or advice, even when it is not welcome or not needed
> (Encarta World English Dictionary 2001)

Let us therefore look at what is considered the key issues in the European 'didaktik-tradition'.

The key questions of 'fagdidaktikk': Why, What and How?

In 'fagdidaktikk', we are concerned with the *Why-question*; i.e. questions about purposes, aims, and objectives of the particular subjects or disciplines (i.e. fag). We are also concerned with the *What-question;* i.e. questions relating to the choice of contents for the curriculum, about what to teach (to achieve the aims). Finally, one is concerned with the *How-question*; i.e. how to organize situations that promotes learning.

These questions are strongly interrelated, as will become clear from the discussion that follows. Underlying, more or less as prerequisite for the discussion, is also the question: *"For whom?"* In the following, the focus will be on the role of science in a *compulsory* and *comprehensive* school, science in a school meant for the whole age cohort. Further up the educational ladder, when there is freedom of choice, and a growing degree of specialisation, the answers to the Why, What and How-questions will necessarily become different.

When we address the questions of Why, What and How, the 'logical' order is to start with Why, i.e. the underlying reasons, rationale and legality, then moving to What, i.e. the selection and organisation of curriculum contents. Then, finally, one may address the more practical issue of How to teach. We will, in fact, reverse this seemingly logical order, starting with the *How*. There are two reasons for doing so:

1. One reason for an interest in the How-question is that the dominant literature in the field of education (also in science education)

has been on this question; The field of education has for a long time been more or less synonymous with educational psychology. Hence, most of the research literature has been centred on what has been called "The American question": How to teach better and more efficient?

2. The problems encountered when looking at learning difficulties actually raises the more basic question of Why we teach and What we should or could teach. Therefore, the initially psychologically oriented research questions inevitably lead us to questions relating to legitimisation and selection of contents of the curriculum. Let us therefore in an over-simplistic way review the history of the HOW TO TEACH-question.

Learning and instruction – many theories and approaches – but little success?

Behaviourism

In the 1960s and early 70s, the dominant theoretical frame was (Anglo-American) behaviourism. Educational research was more or less applied educational psychology, and typical research questions were: How to make pupils understand? How to make teaching more efficient? Is Method A better than Method B? etc. The weaknesses of this approach are (in hindsight!) obvious, and need no deeper analysis here. The underlying theory of learning was questionable for anything but rote learning or acquisition of skills (to fly a plane, to type faster etc). An obvious limitation was that the approach did not address issues relating to curriculum priorities. Behaviourist psychology was, however, strongly anchored to theorising in other disciplines; it was part and parcel of the social debate and political climate. To simplify, this was the era of positivism in the social sciences. From the mid 1970s new directions emerged.

Piagetian stage theory

The behaviourist concept of a one-dimensional intelligence, measured by the IQ, was gradually abandoned, and was replaced by studies using elements of the theories of Jean Piaget. The Piagetian theory of individual growth and development through distinct phases or stages of cognitive functioning represented a new paradigm for framing and answering research questions. There was a stress on conceptual demand and a critical approach to the abstraction level of the subject matter. Key indicators were the use of models, proportional thinking, control of variables etc. The research also resulted in the development of new curriculum materials with more realistic conceptual demands, progression from simple logic to more complex, acceptance that the logic of children is qualitatively different from that of (many) adults. Key persons in this development were Michael Shayer Phillip Adey (e.g. Shayer and Adey 1981). As we can see, the How-question led to a renewed approach to the What-to-teach-question. The basis for making the curriculum was no longer only the 'mother' science discipline as taught in universities. A simple shrinking of university curricula was not good enough.

Personal constructivism

The influence of the theories of Jean Piaget went beyond the notion of stages in development. A basic element in the theories of Jean Piaget was that knowledge is constructed, be it historically (in science as discipline) as well as individually (in the minds of individuals). Similar thoughts came from other theorists in other fields. One may even say that the first uses of the stage theory trivialised Piagetian theory to just another form of IQ testing – simply replacing one number (i.e. IQ) with another label (i.e. Piagetian stage).

Already in the late 1920s Piaget had written in detail about how children struggle to construct meaning and ideas to explain natural phenomena (e.g. Piaget 1929). The development of research in science education in the late 1970s was in many ways a rediscovery and an elaboration of 'the early Piaget'. The research on 'alternative conceptions', 'children's ideas', 'misconceptions' etc. (in the Scandinavian languages: 'hverdagsforestillinger', in German: 'Alltagsvorstellungen') came gradually to replace the dominance of studies on stage development. Seminal publications in this new approach were the works of Rosalind Driver. (See e.g. Driver and Easley 1979. Critical reviews of the literature have been published later, Driver et al 1985, Driver et al 1994.)

This research provided strong (and still growing) research support showing survival of pre-scientific conceptions – also at university level. In spite of mastery of Newtonian mechanics in its advanced Hamiltonian and Lagrangian formulations, the research carried strong evidence that in the minds, the theories and explanations of the students still remained more in harmony with Aristotelian thought. (For a bibliography of such research, containing some 4000 studies, see Duit and Pfundt 1998)

The results represented a shock to many science educators. It became evident that the 'non-scientific' notions of everyday life were practically impossible to eradicate, they survived years of systematic and logical teaching of science concepts. School science seemed to be confined to the school (and exam) setting, whereas the old and pre-scientific understanding continued to be valid alternatives for explanations in the real world of the learners. Research documented a more or less peaceful co-existence of different realms of knowledge – one for schools and exams – the other for the real world.

This state of affairs, of course, could not be tolerated by any serious educator, who basically thinks that the role of schooling (also in science) is to provide the pupils with knowledge and tools that help them act in a meaningful way on the real world. What went wrong? Again, the How-questions had triggered an interest in the What (and also Why-questions). When pupils did not 'take in' the scientific knowledge presented in schools, maybe there was something inherently problematic with the subject matter itself?

These new insights led to new teaching strategies, which can be subsumed under the heading *Personal constructivism*. It may be characterised as an individual approach to learning, often under the heading of *conceptual change*. (See e.g. Posner et al 1982.)

There was an acceptance of the tenacity of prior ideas, and learning was perceived as a process of active construction. The teaching strategy was often like this: Elicit pupil's ideas, elaborate and present the scientific alternatives, confront the pupils with the mismatch – and this conflict may hopefully lead to conceptual change. The results from such approaches are somewhat mixed, and interesting research is going on. But the results are by and large not very encouraging. In the later years, we have seen a widening of the *personal constructivist* perspective:

Widening the perspective: Social and Cultural Constructivism

With the advent of *Social constructivism,* an important perspective was added to the personal and very individual view inherent in personal constructivism. Here, the social environment of the learning is taken more into account; the learner is seen as a part of a group, with collective and shared ways of looking at reality and perceiving the world. The language of the group, the shared meanings, the shared norms, ideals and expectations are seen as strong determinants in the construction process. (We see the connections to modern sociology, like Berger and Luckmans influential book on the "Social Construction of Reality" (1967)) The development in thinking is well described by Duit and Treagust, 1998.

In recent years, the perspective has become even more embracing, and the concept of *Cultural constructivism* has been introduced. Here, science teaching and learning are seen in a wide cross-cultural, international perspective. This approach goes beyond learning theory, it transcends the psychological perspective. With social constructivism, a completely new field is opened for debate. The debate is no longer restricted to efficient teaching, but very basic questions of philosophy of science are raised. Questions now become: How universal and objective is science? What kind of *world-view* is inherent in science – and how does this relate to dominant world-views of that culture? What kind of values does science imply or carry, and how do these values harmonize or conflict with value-systems of other cultures?

As we can see – the research into the seemingly simple question *How-to-teach-for-understanding* has inevitably led us to consider very basic questions of culture and philosophy. We also note how current trends in the thinking in science education are paralleled in the thinking in other fields of research and debate.

Science as a world-view

Let us – again very simplified – present a short version of these arguments, drawing freely on perspectives from key contributors like Rosalind Driver, Bill Cobern, Edgar Jenkins, David Layton and Glen Aikenhead. Science as we know it (often called Western science – a term that in itself raises basic philosophical questions) is a product of a particular culture, and it has implicit and explicit values and assumptions. Some of these values and assumptions may be at odds with prevailing values in different groups of people. This is clearly seen when our 'Western' science science in African or Asian contexts; it is also evident that the world-views of many indigenous groups of people have basic assumptions about life, death and the meaning of life that is different from the accepted scientific views.

It falls outside the scope of this paper to pursue this in detail, but one does not need to go very deep into this matter to understand that we are approaching areas that are both very important and also utterly difficult! If Western science is taught in other cultures, it may be seen as a sort of intellectual imperialism. It may be seen as an attack on the culture. On the other hand: If these cultures want to have the products and material standards of modern developed societies, is it possible to get access to that without offending values, ideas and ideals that are deep-rooted in that culture? Can a 'non-scientific' culture become 'scientifically literate' without committing cultural suicide?

It is not difficult to accept that this is a serious challenge when we talk about other kinds of cultures, and this issue is now considered as a serious one by key science educators in the developing countries (Jegede 1995). We tend to think, however, that we do not have the same problem in our culture, we tend to think that science is part of own culture and that scientific ways of thinking and acting is part and parcel of this culture.

This is, I think, exactly where we are going wrong. My contention is that science, also in our hi-tech and science-based society for most people is a very strange animal. Most people are not very familiar with the conceptual structure of science or with the values, methods, processes and ways of arguing often found in science. Instead of ignoring this fact, one may rather consider this as a challenge to be met. A fruitful approach, elaborated in more detail by others (Cobern 1996, Cobern & Aikenhead 1998) is that science is only one of many sub-cultures in our western culture. It exists side by side with many other sub-cultures. For some pupils, the sub-culture of science is very close to how they see reality. These pupils have no problems accepting the world-view and the values of science. In fact, these young people are the potential scientists and engineers of the future. They are easily assimilated into the sub-culture of science, they accept and internalise the basic tenets of science. Most of us, scientists and science educators, belong to this group. But – and this is the main challenge – most pupils are not at all like that! If our aim is to impose this sub-culture on our pupils, they will necessarily protest (or invent ways of avoiding conflict, like learning to play the examination game without ever believing what they 'learn'). Let us look at some basic elements of the *sub-culture of science.*

The Sub-culture of Science

Values of science – virtues or vices?

Important elements in most programmes in science teaching are "The Nature of Science" or "The Scientific Method". We may start by stating that there seems to be little agreement about what constitutes the Nature of science. The more one digs into the literature of the philosophy of science, the greater becomes often the confusion. In spite of this, we may attempt to describe a few shared characteristics among scientists. Let us examine some of these values or ideals. This is done on in table below by putting up the opposite as a contrast. On the left side we have what may be seen as ideals or ethos of science. On the right we have the opposite, the "anti-thesis". The table is deliberately exaggerated and is mainly meant for debate. (I draw freely on 'classical' sources, like Merton 1942, and more recent ones, like Ziman 2000)

Ideals (?) of science	"Anti-thesis" of science
Depersonalised, non-involvement, detachment	Personal involvement, engagement, Commitment
Cold and rational	Warm and emotional
Value-free, neutral, objective	Value-laden, subjective
Separation of self from reality	Self as inseparable from the rest of the world
A vision that the world is understandable and rational	The world perceived as irrational, mystical, mysterious
No place for myth, 'wonders', miracles, Gods	Sacred and religious
Reductionist, the whole may be understood through analysis of its parts	Holistic, non-reducible, the whole can only be understood 'directly'
Arguing deductively from basic principles	Arguing from contexts and concrete examples
Decontextualized and universal	Context-specific, and particular
Theoretical and abstract	Concrete
Weight on statistical evidence and systematic testing of hypotheses	Weight on personal stories and familiar examples
Systematic, consistent	Unsystematic, inconsistent, ad hoc

Such a simplified table begs for critical questions and debate. One question is whether the above description of science is fair: Is this a proper description of 'real science' – or at least the *ideals* of real science? I do not claim that this is the case in all instances, but rather that science *in general* on many of these aspects is characterised by the left-hand column. Another question is whether the above is (or should be) a description of values underlying *school science*! These questions are important to pursue in more detail, but I here only indicate the nature of such a debate.

The important point is that, for many people, the values or traits on the opposite side of what we have labelled 'ideals of science' appear to be more attractive than the values of scientific rationality. Most people would subscribe to many of the ideals on the right-hand side of the table, *not* because they have some deficits in their thinking, but because they deliberately *choose* to value these traits as human beings. It is also evident that some of the categories labelled as being characteristics of 'science' are more applicable to 'hard science' like physics than to biology. We might even have added 'male' on the left scale and 'female' on the opposite – highlighting some of the issues facing us when we want to address the issue of gender and science education, another topic that falls outside the scope of this paper. The gender aspect is further discussed in Paper III.

Therefore, if the ambition of science instruction is to teach children to think and behave like scientists, we can only expect that this is rejected, or that pupils find ways of encapsulating this kind of behaviour to become only 'school knowledge'. If the ambition is to assimilate children into the sub-culture of science, claiming universal acceptance of these ideals, we can expect rejection and hostility from the majority of pupils. An alternative is offered by a different approach, elaborated in more detail by Glen Aikenhead (1996, 1997 and 2001). He suggests that we should acknowledge the cultural mismatch, and present science as a sub-culture with certain merits and limitations. Then pupils may learn to see that scientific approaches may be chosen *when the situation calls for it*. If they learn to see that a scientific approach has merits in certain situations, then we can leave the choice to the learner. They do not need to change their world-view, belief system and ways of behaving and thinking. This more modest aim of science instruction respects the integrity of the learners and their cultures. The aim is no longer that the learners shall become scientists and internalise the ideals and norms of science. This does not imply that we give up the vision of 'Science for all' or that we give up the idea of having a scientifically literate population. But we do not claim monopoly to our scientific world-view. Let me expand a little on this theme, using the map as a metaphor for knowledge and disciplines.

Disciplines as maps of reality

A discipline or a field of knowledge represents a way of looking at the world. We may compare this with a *map of reality* (Here I take the liberty to assume that reality 'exists' independent of us, well aware that philosophers wage debates over this eternal theme). Different maps can represent 'the same reality'. One map of Oslo can represent the communication system, another map may present the level of pollution, we can have a map of geology, another on topography, and we can have a map with population density or the voting pattern of the inhabitants. Some maps (e.g. for metro or bus-lines) may have distorted scales in order to provide certain information etc. A variety of maps are 'true' in the sense that they represent an underlying aspect of a real world. The maps represent the 'reality' seen through different spectacles (to use just another metaphor!). In real life situations one has to choose map according to the demands of the situation.

The map metaphor can be used for fields or disciplines of knowledge. Science draws up a certain kind of map of reality, but so does ethics, religion or aesthetics. They focus on different aspects of life and reality. In real life, we are not forced to use only one map of this kind. In fact, we shift between these maps according to the situation. Cognitive flexibility allows us to make these transitions smoothly, and most often without thinking about it. A person with only one map of reality is inflexible and narrow-minded. The idea of liberal education is to provide the learner with many different maps of reality, and allowing them to use the one that suits the purpose. A person who knows only one map of reality is a deprived person, and the person who confuses his or her *map* of reality with reality itself, has a problem!

Many pupils may reject science for reasons indicated above. Science is perceived to have the aspiration of defining all aspects of reality, and many pupils dislike this ambition. Moreover, they feel uncomfortable with many of the ideals of science. By presenting science as being one of many possible maps, or as one of many possible subcultures, we may avoid this conflict. We may obtain the goal that pupils come out with respect for science, without having to buy in for everything. Pupils can learn about science just like they learn about other cultures: In our western societies, we want our children to *learn* *about* Islam, we want them to learn to *respect* Islam, but we do not demand (or want!) the pupils to *convert* to Islam. Maybe we should think in a similar way about the teaching of science?

In real life, we belong to many sub-cultures; we take on many different roles, depending on the situation. This perspective may also be worthwhile having in mind when we talk about science education.

Scientific literacy: An international concern!

The educational scene abounds with acronyms. In recent years, new ones have been added, or rather: have become known, since they have been around for some years. These are PUS(T), meaning Public Understanding of Science (and Technology). Similarly, we have S(T)L, meaning Scientific (and Technological) Literacy. In both cases the T for technology is sometimes included, sometimes not.

The implicit assumption when using words like 'public' and 'literacy' is that science and technology is good for everybody, that *all* members of the public in modern society should be literate in science and technology. Our world view is a science-based world view, (or at least, this is what we assume). We like to think that science has pushed back the curtains of ignorance, and has replaced beliefs and myths with verifiable truths. We like to think about our society as a place where scientific knowledge and rational thinking have replaced dogmas and superstition, prejudice.

So one should expect that scientific knowledge is widespread, that most people share the knowledge that our society builds upon, and on which our world view is built. And we like to think that people have internalized scientific attitudes, ways of thinking and 'habits of mind'. We like to think that new challenges are faced in a critical and rational way, not by prejudice, superstition and unjustified emotions. Such are the ideals, and such beliefs are the foundations of visions about democratic participation in decision making.

Among scientists and science educators one hardly needs to argue for the educational merits of science for everybody, in fact we believe so strongly in this that we never even question this as an assumption. Our problem is, of course, that 'the rest of the world' does not see this as self-evident to same extent that we do.

We have witnessed a true explosion in the interest devoted to explore the understanding of science among the general public. We may even talk about an international movement within the field, with people and organizations involved in the defining and measuring of these concepts as well as for identifying causes and elaborating on what might be the best medicine or cure to meet the challenges or to improve the situation. A short introduction to this field is presented in Paper I. In the following, we give some examples and a case story from Norway.

Scientific illiteracy – some examples?

There are many surveys that claim to measure Public Understanding of Science and Technology (PUST). Some of these are mentioned in Paper I. From such studies one may read rather depressing results, as illustrated in the frame below.

Scientific illiteracy? Some possible examples

About 50 % of Americans and Europeans do not know that earth moves around the sun in one year.

50 % of all Americans (and 20 % of Europeans) believe dinosaurs and humans lived together on earth before. (This is – for obvious reasons – called 'the Flintstone effect')

Only 50 % of US citizens (and 69 % of Europeans) believe in evolution, the very foundation of modern biology

50 % of all Americans believe in incarnation – that this life is only one of many lives to follow

66 % of the adult European population does not know that ordinary tomatoes contain genes.

53 % of Europeans consider Astrology to be 'rather scientific'

The majority of Norwegian 13-year think that 'atoms' means bombs, radiation and danger

Questions used in surveys are often repeated in other countries for comparative reasons. The international literature demonstrates that the phenomenon is worldwide, but with interesting cultural variations. The distrust in evolution, as indicated above, is mainly a US 'phenomenon'.

Scientific illiteracy and anti-scientific movements

The concept of scientific literacy (often in its negative form; 'scientific illiteracy') has become recognized as an important societal challenge in many countries. In the new Norwegian Core Curriculum (KUF 1997), the following is a key statement:

> The flow of technological facts and findings requires learning to avoid 'scientific illiteracy' – the inability to comprehend words like 'gene splicing', 'ozone layer', or 'immune system', and what social consequences they augur. (KUF 1997, p 28, available at http://skolenettet3.ls.no/L97_eng/Curriculum/)

The above statement – although not distinguishing between science and technology – also indicates an important underlying concern, which may be seen as a great paradox in present society: The fear that the general public will become 'strangers' in their own reality, without the possibility to comprehend the situation or to take part in public communication and to act rationally. We live in a society based on science and technology and we are surrounded by scientific concepts and science-based products in private life as well as on the workplace. Indeed, in the Nordic countries, we are greater consumers of PCs and cellular phones than in most other places in the world. But yet, and this is the paradox: We have, also in our countries, a growing movement of anti- and quasi-science, ufology, astrology, magic, occultism, mysticism, palm reading, tarot cards, pyramid energy, crystal power, etc. There is no limit to the fantasy, and every wild idea seems to have a market!

If one visits bookstores, one is more likely to find books on astrology that on astronomy – and many people, including teachers, do not know the difference! And the shelf for 'alternative philosophy' is often centrally placed and more voluminous than the shelf for 'real philosophy' – even in university bookstores! It is said that in Paris, there are more healers than doctors, and surveys show that in the US, 50 % believe in miracles by prayer. Some years ago, when there was a serious draught in the US, President Reagan on TV urged the whole nation to kneel and pray to God for rain at the same time – to increase the synergy effect. Maybe we should not laugh at the 'rain dance' of the Native Americans? It was also said that Reagan's wife, Nancy, used an astrologer as a key advisor. Chinese rulers did the same – centuries ago.

Our time and age have received many names, the space age, the atomic age, the information age. Maybe a better term is to give in and admit that it is really just 'New Age' or that we are entering the 'Age of The Aquarius'? We have to admit that science and technology, at least in Western democracies, are met with distrust and suspicion, and that there seems to be a falling interest in science in schools. Norwegian data show declining enrollment in schools, especially in physics, and we are facing recruitment crisis in the whole sector of science and technology. Similar trends are visible in many OECD countries.

We seem to have, in many Western democracies, an anti-science and (even more?) an anti-technology movement. It is, however, important not to treat all 'alternatives' as equally dangerous (if that is what they are!) Some may be rather sound reactions to trends in modern society; some are rather harmless and even well intended reactions. Some tendencies are based on simple stupidity, others on ignorance or wild fantasy, while others are more deep-rooted and deserve serious attention. This is not the place to sort out these different tendencies and their underlying assumptions.

When looking for causes for deplorable situations, one usually turns to schools and teachers. I do not think that this is fair, neither in this case nor in most of the other cases, where the school is blamed for societal problems. The anti-science movement has more profound societal reasons, reasons that should be taken seriously and addressed with great concern. But I think that the school has a role to play in counteracting these tendencies, that the school could and should be a place where critical analysis and systematic approaches to knowledge was possible. In the present media-driven society, the role of the school in such a context is probably more important than ever before.

S&T in primary schools, a sad story of Norway

In the light of these expectations to the role of schooling, the situation is rather disappointing, at least in Norway. From a recent official review of science in Norwegian schools (for a short English version, see Sjøberg and Jorde 1995), we find that the primary stages are dominated by teachers who have managed to avoid science through their educational careers, both in school and then in their in teacher training. Such teachers have to rely heavily on the textbooks, and we found that even textbooks were written by people without any background in science. Even the official national approval of textbooks (a unique Norwegian institution, until it was abandoned in 2001) was done by persons without science background.

The result is that we have had textbooks which abound with misconceptions, mistakes and prejudice. Some examples of actual mistakes cited from the most widely used textbooks are presented in the frame below.

Quotes and 'definitions' from Norwegian textbooks (published by Norwegian University Press) used until 1999

Energy = force

Watt = strength of light (textbook, grade 3)

Watt = strength of current (same book, grade 4!)

Magnetism is a force found in iron

(The accompanying illustration shows a bar magnet with nails and paper clips attracted to the middle of the magnet!)

The moon is a mirror star

Glaciers are remains from the ice age

Bacteria are viruses

Bacteria: cells that make you ill

Temperature = heat
(All accompanying illustrations show mercury thermometers, forbidden in schools a long time ago)

Electricity: lack of "something"

Electricity for use in the home is rubbed off in power plants when big wheels turn fast (i.e. just like the rubbing of balloons against dry clothes, also shown on a picture on the same page!)

Textbooks always convey ideological messages, sometimes hidden and implicit, sometimes open and explicit. Analysis of hidden ideologies is often a difficult task. For an interesting Swedish study, see Östman, 1995. Knain (1999 and 2001) has used similar methods for analysis of Norwegian curricula and science textbooks. In the case of the above-mentioned textbooks, the analysis is, however, very simple. The authors have not done any attempts to hide their prejudices.

A strong underlying ideology in these textbooks is a romantic view of Nature. Nature is depicted as harmonious and inherently good. Colourful drawings show the Harmony of Nature, where all living creatures live in peace together. (There are no pictures of animals eating other animals, and no indication that anything 'natural' may be poisonous or dangerous!) The old-fashioned (and nonexistent) farm is presented as a kind of ideal.

On the other hand, the textbooks present a picture of Man as an intruder and destroyer of this natural harmony. The following quotes from a textbook are symptomatic:

> Chemicals do not belong in nature. People have made them in an artificial way ... Waste that belongs in nature, will be broken down and become useful. But nature does not want the manmade materials. They do harm to nature. (Norwegian science textbook, grade 6)

This quotation (in addition to the scientific misconceptions) reveals an animistic or spiritual view on nature, and how it is attributed human traits. Books like these passed through the official ministerial textbook approval process that was required until 2001.

These textbooks rarely considered human production, industry or technology. The textbooks depicted a strange world: All 'things' and products of modern society were present – but there was no indication that they were actually produced or made by anyone. To the extent that industry and factories existed in these textbooks, they 'produced' pollution – not products.

It is important that teaching and textbooks encourage critical attitudes and skepticism. In this case one seems to have confused a *critical* attitude with a *negative* attitude – which indeed is not the same! In the attempt to be 'politically correct', the authors have replaced reflection and criticism with hostility and prejudice.

It is, however, positive to note that the critique in the national reviews has been taken seriously by the ministry, and that curriculum reforms introduced in 1997 has improved the situation considerably. (The reform is called L 97 and the new curriculum is available in English at http://skolenettet3.ls.no/L97_eng/Curriculum/)

Scientific literacy: Three possible dimensions

The term 'scientific literacy' and 'public understanding of science' are used frequently, and often without a precise meanings. We will not here try to establish firm definitions, but rather reflect on possible dimensions of these concepts.

What is it about science the 'the public' should know? Is it a list of 1001 things that science 'knows', and hence everybody else ought to know as well? When glancing through the research and documentation, one may get this impression. Chinese researchers in the 'PUST tradition' often take the list of knowledge items used it the US and find that the Chinese peasant knows even less about the number of planets in the solar system than the American citizen. So what? Is that what the Chinese (or indeed also the American) 'man in the street' needs to know? The question is rhetorical. The answer is of course: no, there is more to scientific literacy than the collection of facts. And if facts are important, maybe the list of important facts would be different in different societies? To draw attention to the culture- and context-dependency of scientific literacy, we may precede it with the term 'functional'. By doing so, we suggest that that the understanding should help you to function and to take an active part in your society.

For analytical purposes, we may operate with three different dimensions in a concept of 'functional scientific literacy':

1. Science as a Product:

Science has through its development produced an impressive building of concepts, facts, laws, models, theories. Although these are human constructions that are subject to change and modification, one may assert that scientific knowledge is fairly stable and cumulative. It is not very likely that the basic elements of present science will become obsolete and replaced during a 'paradigm shift' in our lifetime (or of our students).

2. Science as a Process:
Science is not only knowing facts and answers, but it also involves powerful ways of finding solutions and approaching problems, getting, analysing and judging evidence. Although there is little agreement about what exactly constitutes 'scientific method', there is at least agreement that processes, methods and procedures are integral elements of 'science'.

3. Science as a Social institution:
Science today is an important element in society. The scientific community have millions of people as members. These have values, norms, ideals, they have their institutions and organizations, and they have their own interests and priorities. They are also part of society, they receive large sums for doing their work, and their activities depend on priorities made outside their own community. Science is shaped by society – and science is in its turn shaping society. An understanding of science today is unthinkable without some understanding of how its 'internal' and 'external' mechanisms interplay.

Striking the balance?
The above three dimensions should all be reflected in a valid concept of public understanding of science as well in the school science curriculum. Let us briefly characterize the situation for school science. (see also Paper I)

Traditionally, we have had a dominance of the first category; an emphasis on the products of science, often the well established and uncontroversial elements. This has given school science an aura of eternal authority, where there is no room for doubt, human values and personal judgement etc. This may be a very comfortable image for the scientist or the science teacher – but it is certainly not very attractive to many young people, and in particular not to girls who want to engage more in issues of personal relevance.

We have had some movements towards the second dimension above; the process side of science. The intention has been to give a more challenging and also more authentic image of science. Slogans like 'enquiry' and 'discovery' science, 'hands on' science etc. became abundant, and well-known projects followed this rationale for renewal of school science. The process dimension has a key role in many of the curriculum reform projects, but has not had a strong impact on most mainstream teaching (or exams!).

The third, the social dimension, has not yet been taken so serious, and is likely to be very difficult and controversial. Science has many roles in modern society, how do we approach these challenges, shall we go for a 'whitewash' of science, or shall show even the more problematic sides? My personal conviction is clear: I think we should explore also the 'darker' or problematic sides of science. This is partly a value-based stance, but it is also my firm belief that more young people will be attracted to science when the complexities are revealed and not concealed.

The image of science that is presented in curricula and elsewhere is important – but far from non-problematic. Whose image of science should we present? Even among philosophers of science, there seems to be little consensus about what constitutes the Nature of science (Alters 1997) – let alone what constitutes a balanced treatment of its ethical and societal aspects.

Recent moves in the direction of STS-teaching are promising for new development in the teaching of science, but this a field where little agreement seems to exist. (See Aikenhead and Solomon, 1994). Still, maybe this social dimension of science can be seen as the most important for the public in the future society?

In this context it may be interesting to note that the ongoing OECD PISA project uses the following definition of scientific literacy:

> Scientific literacy is the capacity to use scientific knowledge, to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity. (http://www.pisa.oecd.org/pisa/science.htm)

We note that this definition (and the following more detailed explanations and clarifications) puts weight on the two first aspects of scientific literacy as suggested above. But in the PISA project, knowledge about science and society and the role of science (and technology) in society are *not* included in the definition of scientific literacy. The exclusion of this dimension is of course not arbitrary. Science education thus remains an induction into the contents and processes of science – students are apparently not supposed to learn *about* science, or to be *critical* to S&T as social institutions-.

Reversing the PUS -question?

The issue of public understanding of science is often framed in an implicit context that the ignorant (or even illiterate!) public needs to be 'informed' about science. The task is conceived as telling people what we already know, that we should share our wisdom with the ignorant receiver. The research communities are concerned with bringing science to people and to 'popularize' their research findings.

There are many reasons to question this approach. One reason is related to pedagogy, based on what we know about learning: Learning does simply not occur by 'uninformed' people being told by 'informed' people what they should know. Even in schools, real 'learning' seldom happens like this. Maybe such a thing happens for exam purposes, but such learning seldom becomes 'meaningful knowledge' that is used outside the classroom. Most often, such 'knowledge', is forgotten when the exam paper is finished.

For the adult population, the pedagogical challenge is even greater: No one will deliberately enter a situation where are they are treated as ignorant, and willingly ask to be informed by academics – unless they have very good reasons for doing so. Communication is always a two-way process, and some sort of mutual trust and relationship has to be established – motivation to learn must be real. For the general public, there are no 'motivating' exams at the end! When communication fails, one should not always blame 'the receiver'. Maybe one should turn the PUS issue upside down:

> *Instead of asking how well the public understands science, one may ask for how well science understands the public!*

There are many interesting studies of how the encounter between 'science' and 'the public' can be when the terms of communication are different from the informer-receiver format. (See for instance, the case studies in Layton et al 1993). Another approach is the concept of 'consensus conferences' where ordinary people (i.e. non-scientists), are invited to take a stance on important issues where scientific knowledge may be an important element, but where the involved people themselves define their need for information and seek expert advice based on their needs and priorities.

Four good arguments for science – or convenient ideology?

Let us now return to the statements given at the beginning of this article; the four types of arguments put forward in support of science as part of the education for everybody? Let us go in some detail on the four arguments put forward at the beginning of the article and take a closer look at their credibility.

1. The economic argument

In short, the argument is this: Present society is characterised by high-technology production, often called knowledge industry. There is a tough international competition, and the labour-force needs a high level of scientific knowledge and skills. These arguments may, however, be challenged with the following counter-arguments:

Firstly, we may argue that industry today does not require *scientific understanding*, but rather *technological skills*. These skills change rapidly, they are seldom deduced from or dependant on basic scientific understanding, and many of them are highly specialised and may probably be better learned at the workplace than in the school curriculum.

Secondly, when we look at our present society, we see that the most successful careers are *not* in science, but rather in law, business, administration, banking etc. Lawyers and economists do not exactly excel in their understanding of basic science, but this does not seem to have been an obstacle to their career! (One could, however, argue that a magistrate in court, as well as a jury, *ought* to have basic scientific literacy to be able to sort out the kinds of evidence and proof that are brought to court – much of which is to an increasing degree based on scientific, technological and statistical reasoning!)

Thirdly, if we look at the research evidence, it is hard to see any clear-cut connection between the level of scientific understanding and the economy. As noted in the above argument, there is little evidence of a connection between science background and economic success on the personal, individual level. But, more surprising, is that even on the national level, the argument is questionable. The most prosperous economies (like the US) are not always those with a high public understanding of science. There seems, however, to be agreement that the *general* level of education is important, and that there is a need for an elite in science, but not necessarily a widespread public understanding of science.

2. The utilitarian, practical argument

In short, the argument is this: Scientific knowledge is the best tool to interpret and understand the world, both the natural and the man-made (sic!). We live in a science-based environment, and scientific understanding makes you act and perform better. Let us raise some counter-arguments:

The first counter-argument is as above: Are we not again confusing science with technology? Is it not the mastery of techniques, equipment, tools and gadgets that help you in daily life? Does knowledge in *basic science* help you perform better in a world with remote controls, pushbuttons, electronic calculators and digital watches? Consider some practical examples:

- Does Newtonian mechanics make you a better car driver - or even a better car mechanic?
- Does binary logic and semiconductor theory improve your computer skills?
- Do Maxwell's equations help you repair electric or electronic devices?
- Do bosons, fermions and quarks help you act in *practical* situations at *any* time?

Let us push this critical argument one step further: The research literature in science education abounds with descriptions of so-called 'misconceptions' mentioned above. These are ideas that pupils have, but ideas that are at odds with established scientific ideas. These 'non-scientific' ideas prove to be very resistant towards teaching, a fact that is considered to be one of the most serious challenges to science educators. Maybe we should ask the impertinent question: Could it not be that pupils hang on to these ideas simply because some of them are rather functional in everyday life? Maybe they describe reality quite well, give expected results, are socially accepted and correspond quite well with everyday language? In the frame below are some examples where one may argue that 'established science' is at odds with everyday notions, and where the 'misconception' even may be more functional.

Everyday language and 'misconceptions' versus established science:

- **In everyday language, the 'Sun rises' in the morning, but in science the Earth rotates ... (Try to reformulate the above to be more 'scientific'!)**
- **In everyday language, we talk about 'penetrating eyes', and we 'throw our eyes' on things we see, and 'let out eyes slide along the horizon', but in science the rays enter the eyes ... (Again: try to reformulate!)**
- **In everyday language 'the cold' creeps into the house, but in science neither heat nor cold 'exist ', but are consequences of molecular motion ...
(Again: try to reformulate!)**
- **In everyday language, we do work when we carry a heavy suitcase, but in science we do not work when the floor is horizontal, and when we go down stairs, it is the suitcase working on us!**
- **In everyday language, 'the motor pushes the car', but in science it is the ground that is exerting the force on the car!**
- **In everyday language we 'use electricity', but in science the electricity is not *used*, everything goes back to the power plant!**
- **In everyday life we 'pay for the use of energy', but in science energy is not *used*, but always *conserved*!
(In physics 'conservation of energy' means something different than the ordinary use of the term!)**
- **Pure water (only H_2O) in Chemistry is not like the 'pure water' we like to drink!
(With dissolved air, minerals etc.)**

The tension between everyday concepts (and everyday logic) and scientific concepts (and logic) is an area that has attracted a lot of concern recently. Book titles like "The unnatural nature of science" (Wolpert 1993) and "Uncommon sense: The heretical nature of science" (Cromer 1993) indicate the perspectives. Even people who have devoted most of their lives to the improvement of science education, become disillusioned and publish books where Scientific Literacy is called "a Myth" (Shamos 1995). It is likely that science educators have underestimated the difficulties we are facing when trying to convince pupils about the usefulness of scientific knowledge. We have treated scientific knowledge as a form of common sense, based on simple and clear-cut observations. Many critics argue that this is a serious flaw, both from a philosophical and from a psychological perspective – but this is not the theme of this paper!

To summarise the counter-arguments: Science uses theoretical and non-observable concepts to describe an idealised (and therefore 'non-existing') world that is without gravity, without friction and without air. Hence it is no wonder that science is not very practical!

3. Science for citizenship

In short, the argument runs like this: When looking at the long list of challenges facing society today, we are struck by the fact that most of these are science-based. (Examples: genetic engineering or screening, energy issues, environmental issues, use of natural resources, protection of the environment, health and safety issues, pollution, radiation risks, allowed additives and treatment of food etc.) We select our politicians on the basis of their stances to such issues, and informed decisions in a democracy requires knowledge in the science behind such issues – from the voters as well as from the politicians. There are good reasons to hold on to this argument, but we may raise some doubt and consider some counter-arguments even here:

In important cases like the examples given above, the science involved is often too complicated to understand, and we know that even the scientists disagree on most of these issues! (For many people, disagreement among scientists is confusing, they expect that science always provide clear-cut answers. There is a clear need to include more about the nature of science and scientific discourse in the science curriculum and in the non-formal presentations of science through media.) It is simply impossible to be updated on these issues, and even the best scientists are often only well informed within their own narrow special field. A somewhat weaker position on this issue would be that the public should have some ideas about what constitutes a valid argument, and that they should be able to judge from the arguments *which* 'experts' they would rely on.

A more important objection is that most real decisions on such issues are (and should be!) *value-based* and socially based and not science-based. Indeed, it is very seldom that we may conclude on *scientific* grounds on such issues. Some people think that this is possible, and that it is possible to ' deduce' correct policies on the basis on valid science and available technologies, and that one may reduce political questions to become scientific questions. Such positions are sometimes called 'scientism', and in its strong version it becomes a kind of 'techno-fundamentalist' position, which in fact may be equally dangerous as other, mostly religious, fundamentalist positions.

Even in a weak position, the experience from some STS (Science, Technology and Society) teaching material is that when pupils are invited to discuss political issues where there is a scientific knowledge base, it has been shown that the science very quickly becomes subordinated the more value-based consideration (Gaskell 1994). These issues are explored in detail by Kolstø (2001) in his PhD thesis.

If we accept that science education should aim at providing pupils with a background that enables them to understand current issues of social and political debate, even an elementary analysis of science curricula and textbooks reveals that this has not been the guiding principle for their construction.

4. Science for cultural literacy

In short, the argument is this: Science is a major element in our culture, it has shaped our 'world view', it is strongly connected with our philosophical thinking, and it embodies *ideals*, *norms* and ways of thinking that are at the heart of our culture. Modernity, rationality and enlightenment are key elements in our society, and these are inherently connected with scientific thinking. Science is one of mankind's greatest cultural products, and any notion of an educated person in modern society should include an encounter with science as a human endeavour. Key words in educational debate are 'dannelse' in Norwegian or Danish and 'bildning' in Swedish and German (it is interesting that this concept does not exist in English, at least not in a direct translation!)

The counter-arguments are widespread, and maybe even more 'accepted' than for the first three dimensions. Many hesitate to see science as part of culture. They will raise their eyebrows and ask: Is science *culture*? Do the ideas and thoughts of people like Galileo, Newton, Einstein, Darwin, Bohr etc. belong to our *cultural* heritage? People will ask: Is knowledge of evolution, atomic principles, relativity theory or of Big Bang part of *culture*? For many 'cultured' persons, science (and even more so: technology!) is indeed considered to be rather the *opposite* of culture, and 'cultured' persons may even prove their cultural superiority and status by demonstrating ignorance in science and (more so) helplessness versus technology. (Scientists may not obtain the same cultural status by claiming ignorance of Mozart and Shakespeare!)

This asymmetrical relation between people from the sciences and the humanities was noted by C P Snow nearly 40 years ago in the famous essay *The Two Cultures and the Scientific Revolution* [1959]. He wrote: "Literary intellectuals at one pole — at the other scientists....Between the two a gulf of mutual incomprehension." The cause for concern may be even greater today.

As can be understood, this author has sympathy with this cultural argument. It is, however, not without problems, stemming exactly from the above assertion that science is not 'culture-free', but a part of our own culture. Science as we know it today is a cultural product of modern (western) society. Hence, it also carries with it other cultural connotations, values, ideals, norms. (In one way, this is exactly why we want it to play an essential role in the curriculum!) But this embeddedness in a *particular* culture also poses problems for many learners, especially for those having different cultural backgrounds. For them, learning the celebrated values and norms of science may be seen as an attack on their own culture as mentioned before.

The issue of the cultural underpinnings of science also have strong *gender aspects*, and the feminist critique of science raises serious questions relating to this issue (see, e.g. Harding 1986, 1991 and

1998). The basic idea is that well-established science is basically a male construction, and that this manifests itself in many ways. It should be noted that this critique ranges from a 'mild' criticism of research priorities to a rather profound critique of the basic epistemology of science as we know it today. It is interesting to note that in the above-mentioned UNESCO World Science Report for 1996, a special chapter is devoted to this issue – also written by Sandra Harding. These issues are treated in more detail in paper III.

The different cultural issues of science and science education are explored more in detail in the International handbook on science education (Cobern and Aikenhead, 1997)

Conclusions?

Academics make a living out of making the apparently obvious problematical, and we are often not in the position where we are responsible for the day-to-day running of an education system. Still, I think that a few more constructive points emerge from this discussion in this paper:

Firstly: We should take not to 'oversell' science with unjustified aims, claims and promises! We should realise that when young people reject science, they may have some very good reasons for doing so. These arguments should be taken seriously and should not be dismissed, ignored or ridiculed. And maybe we should shift the focus away from the utilitarian arguments and put more weight on science for citizenship and for cultural literacy? Such a shift may have profound implications for the S&T curriculum as well as for teacher training.

Secondly: We should face the fact that the many aims of science education the compulsory part of schooling may be incompatible with each other – and in some ways also unattainable. Different curriculum emphases may be in conflict. A re-examination of the aims may shift the emphasis from being an attempt of assimilation into the subculture of science towards science education as an orientation about the World-view, values and methods of science – and the strengths and limitations of these. With such a perspective, science will become a sub-culture of which we can cross the border when the situation calls for it. Or, put in another way, science can become a source that may be utilised when we need it: "A repository to be raided for what it can contribute to the achievement of practical ends" (Layton, et al 1993, p. 135).

Thirdly. We need to strike a better balance between the above mentioned three dimensions of scientific literacy. Although there has been a shift from the contents to the process dimension, the social and political dimension of S&T are still ignored.

Fourthly: Current debates about changing perspectives and rethinking of aims may be subsumed under a broad umbrella with the acronym STS (Science, Technology and Society). The approaches differ, but we may have to abandon the aims of an encyclopaedically coverage of science contents. Assimilation into science may then be replaced with appreciation of science, acceptance of science – or at least tolerance of science as a worthwhile activity for some people and as a legitimate part of our society. Unless science educators and scientists accept the problematic nature of their brave enterprise to bring science to everybody, Brian Wynne's (1996) statement that "scientific institutions are often their own worst enemy" may become a true prophesy.

References

(Placed at the end of this publication)

Paper III

Gender and science and technology education

Svein Sjøberg

Contents

Background

This paper is based on an invited contribution to the conference *Promoting Public Understanding of Science and Technology in Southern Africa* at the University of Western Cape, South Africa. (The original paper is published in Ogunniyi 1997). In this revised and updated version, the direct connection with the situation in Southern Africa is partly removed[1] but the situation in developing countries is still a focus.

This paper will inevitable be coloured by two facts from which I can not escape:

1: I am a man, and

2: I live in a rather privileged country in the North.

Setting the scene – some paradoxes

Let us start by putting the issue of gender and science education in a wide context by raising a few paradoxes:

1.

Education is the single most important factor for development. Even the World Bank states this as a fact: *The economic returns to investments in education - as measured by productivity and income - are higher than these in physical capital and are essential to the successful investments in other sectors of the economy.* (World Bank 1990).

> **Nevertheless:** Education gets a small share of the economy, especially in developing countries. And the proportion of foreign assistance going into this area is rather small for most donors. (UNDP 1990-2001)

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1 A comprehensive review of African initiatives and experiences relating to gender and science in Africa is given in Jenkins (2000), in particular by Mulemwa (2000), who has been a key person in many of the later initiatives in SMT education in Sub-Saharan Africa.

2.
In the education sector, basic education (primary as well as non-formal basic education) is the best investment, also measured in purely economical terms. Analysts operate with rates of return around 20 % (Hallak 1990).

> **Nevertheless:** The input from both states and donors in this area has until recently been meagre compared with other levels of the education system.

3.
The International Convention on the Rights of Children, signed in 1990 states: *The child has the right to education, and the State's duty is to ensure that primary education is free and compulsory. .... The State shall engage in international cooperation to implement this right.* (para 28)

> **Nevertheless:** The state in many developing countries puts fees and other economical burdens on primary school children and their parents. The first to be taken out of schools are likely to be the girls, a fact confirmed by enrolment statistics..

4.
In the area of education, the education for girls and women are the most important for a series of important challenges (to lower the number of births, to improve the health of family, to promote the education of the children, to increase family income etc.). James P Grant, previous general director of UNICEF, puts it this way: *Literacy of women is the most important single factor in the reduction of mortality of children. The children of more educated mothers have a greater chance of survival and of healthy growth than those of the less educated or illiterate.*

> **Nevertheless:** On a global scale, girls and women have less access to education than boys and men – especially in developing countries. In many industrialized counties, however, girls today get (or rather: choose to take!) more education than boys.

5.
Education in science and technology are (in addition to basic literacy and numeracy) the most important areas of the curriculum to enable people to make sense of the world and to use the resources at hand.

> **Nevertheless:** It is exactly in science and technology that girls and women have the lowest access. This situation is *not* confined to developing countries, but is to a varying degree a worldwide phenomenon.

Each of the above statements would deserve long arguments and could be backed up with statistics and research evidence, which goes far beyond the scope of a paper like this. The starting point is simply to draw attention to the fact that although there seems to be strong arguments and a widespread agreement for promoting the access of girls to science and technology, the situation is that this area is exactly the area where girls are most neglected, discriminated and under-represented. With some interesting variations, this seems to be the case in most countries and cultures.

It is a paradox that very often the issue of women in science and other realms of life is treated under the same heading as that of minorities and marginalised groups. One seems to forget that girls and women are not 'a minority', but constitute more than half of the world's population. Moreover, it is asserted that they perform more than half of the work in the world: *Of the total burden of work, women carry on the average 53% in developing countries and 51% in industrial countries.* (UNDP 1995, p 6)

Initiatives and Statistics: Making the issue visible

Basic education has been put as a high priority in recent years, mainly through the World Conference on Education for All (EFA) in Jomtien in 1990, and the policy and action plan that was adopted there (UNESCO a. o. 1990). This has led by a shift in priorities, both by countries and by donors (Lockheed and Verspoor 1990). The World Bank has more than tripled its lending to basic education in the years after Jomtien. In April 2000, the World Education Forum, in Dakar, Senegal, assessed the progress that had been made. (Documented and analyzed by UNESCO 2000, available at http://www.unesco.org/)

The EFA initiative has put education for girls as a main focus. This emphasis was strengthened by The Fourth International Conference for Women in Beijing in 1995 and several other follow-ups in the years thereafter.

It is often only when you put numbers on issues that they become 'real' and are seen and heard in the debate. There is still a lack of reliable statistics divided by gender. The plea for statistics where gender was a visible category was strong already in the World conference for women in Nairobi 1985, and there has been a steady progress since then. The issue was further focussed by UNDP (United Nations Development Programme) when they defined their HDI (Human Development Index) in 1990 and further developed a *gender-sensitive* HDI in 1991. This index forcefully drew attention to the gender gap in most countries. UNDP has further elaborated both the statistical procedures as well as arguing for better data.

In 1995 the focus of the UNDP report was on gender equity. This report introduced a new index for gender equity, called GEM: *Gender Empowerment Measure*. The GEM is a composite index that incorporates issues like female participation in public life (government, parliaments etc.), private ownership, salaries compared to men etc. By regular reporting and 'ranking' of countries on their performance these two indices of gender equity, UNDP helps in creating a political atmosphere where this issue becomes visible.

UNESCO has world-wide responsibility to provide reliable educational statistics. This is printed in annual yearbooks, and made available through their web-site. A more analytical approach that just giving data is made in the 'World Education Report', published biannually since 1991(UNESCO 1991 ... 2000). The focus in the 1995 report was on education for girls.

Similarly, UNESCO publishes a comprehensive 'World Science Report', also biannually. It is interesting to note that the 1996 volume devoted a whole chapter to 'The Gender Dimension of Science and Technology' (UNESCO 1996). Even rather strong feminist critique of science was printed in this report. For more literature on statistics and documentations through research, se Paper I.

Gender: A problematic concept?

In the last decade or so, the term 'gender' has essentially replaced 'sex' or 'sex roles' in the discussion of girls and boys in education and other fields of social science. The reasons are many. An obvious reason is the unwanted sexual connotation of 'sex.' But there is a deeper reason. 'Sex' directly refers to the *biological* nature of the classification of people. The phrase 'sex roles' for some time referred to the *social* and acquired nature of the observed differences between girls and boys. For different reasons, 'sex roles' was found to be unsatisfactory. Then the term 'gender' became prominent, a term normally used in grammar to signify a grammatical status of nouns. In the context of girls, boys, and science, the term 'gender' is now frequently used. (It is interesting to note that the G in GASAT changed from Girls to Gender around 1985.)

The term 'gender' has two obvious advantages. Firstly, it does not have unwanted sexual connotations. Secondly, it refers to the social nature of the issue. For an analytical tool, both reasons are important. The distinction between sex and gender also indicates that femininity or masculinity are not biologically determined, but are socially constructed or negotiated, and that they may change over time and may be different from one culture to another.

But the usage of the terms sex and gender is by no means consistent in the literature. This fact is recognized with some regret in newer dictionaries. (Encarta Dictionary (2000) states: *gender is often used euphemistically to avoid the word sex*). Hence, more than often, we see the term gender used even in the strict biological sense, as when asking for 'gender': (girl or boy) in a questionnaire. We probably have to live with this confusion, although the concept gender has lost some of its original strength as an analytical tool. (In this paper, the usage is by no means consistent!) It should also be noted that the distinction sex vs. gender does not exist in all languages.

Research and reviews of research

The traditional way researchers explore a field is of course through literature searches in library databases like the ERIC system, either through CD-ROMs or on the internet.

One may of course also try more general internet searches. One may for instance use one of the now competing 'search engines' (like AltaVista, Google, Fast, Yahoo, Copernic etc). These engines use different techniques to search, validate and index several billion documents on millions of servers worldwide.

To get an overview of the available volume, I started with a search on *'gender AND science'* and came up with more than 30 000 hits! The more narrow search: *'gender AND science education'* gave more than 1 000 hits, while adding *'AND Africa'* to the search reduced the hits to some 200 hits, still a rather high number. When browsing through these sources, one finds that rather few of the servers are actually based in Africa. Rather, they take you mainly to two different types of hosts:

1. Universities in the north, often presenting (and offering) their expertise in the field.
2. International organizations, like UN organizations and donors.

Although these sites are powerful sources for information and debates, the very fact that they (except some UN sites) are based in the North again demonstrates that new technologies are likely to widen the gap in technology between the North and the South, maybe even more than the more traditional industrial technologies did. When adding the fact that access to (and familiarity with) the new information technology is even more gendered that most other fields, this is just another illustration of both the N-S and the gender divide. The 2001 issue of the Human Development Report had the theme *Making new technologies work for Human Development* as focus, and gave special attention to the gender issue in such a context (UNDP 2001).

The research literature on gender and science education is rich. All science education journals publish such articles regularly. The best way to enter the field is probably through books and review articles of the field. (e.g. Kahle and Meece 1994, Rennie et al 1996).

Cross-cultural and feminist critiques of science:

People working in the sciences (and often also those in science education) consider science (and school science) as something taken for granted. For them, science is clearly defined and non-problematic. To be induced in this view is often an implicit part of being trained as a scientist or a science teacher. Few scientists get to know much about the history and philosophy of science, let alone the more sociological critique of science. One may even argue that assimilation into the existing paradigms of science is efficient for the smooth running of the scientific enterprise. Even Thomas Kuhn (1962, 1970), who introduced the concept of 'paradigm shifts' and gave critical description of the development of scientific thought, argued that such an induction into traditional and established thinking was functional for the development of 'normal science'.

But, there is a long-standing criticism of science. The critique comes from a variety of positions and addresses many different agendas. The critique also varies from a mild criticism of priorities of research agendas and the misuse of scientific results to a more fundamental critique of the ontological and philosophical assumptions underlying science. Some critics go very far in their rejection of currently accepted science. With such a position, science is reduced to be a subjective account of nature, emerging from a particular group of people pushing the subjective interests of their own power group. It falls beyond the scope of this paper to do justice both to the critique and also the response to the critique. The theme is a little elaborated in Papers I and II, also with references to recent literature. I will therefore limit myself to describe my own position on this dimension, and see how that critique may be of help in addressing the issue of gender and science education.

It seems to me that one may benefit from the critical analysis of science from both a cultural, political, social and indeed, gender perspective – but without lapsing into complete solipsism, relativism, subjectivism (and hence rejection) of science as we know it today.

Science has to be understood as a cultural product of creative thinking up through the history. It has been shaped by people trying to make sense of the world. It has grown and prospered in particular societies with particular cultures, and bear the strong mark of cultural assumptions, values, languages and metaphors of these cultures. It also bears the mark of the particular dominant groups in these societies.

A rather non-controversial version of this view was voiced by the very influential sociologist Talcott Parsons:

> Science is intimately integrated with the whole social structure and cultural tradition. They mutually support one other—only in certain types of society can science flourish, and conversely without a continuous and healthy development and application of science such a society cannot function properly. (Talcott Parsons in The Social System, ch. 8 1951).

Ruth Hubbard, a well-known American biologist, makes a stronger stance:

> But since, in fact, they (the scientists) have been predominantly university-trained white males from privileged social backgrounds, the bias has been narrow and the product often reveals more about the investigator than about the subject being researched. (From 'Have Only Men Evolved?' in Women Look at Biology Looking at Women)

A much stronger feminist position is this:

> ... the mechanistic metaphors and models of nature that were so valuable to early modern European scientists carried class and gender meanings for them and their culture. These meanings helped to shape the patterns of European expansion to which these sciences contributed (McGregor and Harding in UNESCO 1996 p 304).

Statements like these place science as a human product alongside other cultural products. This placement is a challenge, and it opens up for a series of different discussions and a series of possible positions to take. But such a view does not necessarily lead to a rejection of science as (merely) a Western product, or as a purely Male product. There are interesting historical accounts that describe how science came to be defined as a male territory (e.g. Schiebinger 1989 and 1993). An acceptance of the cultural roots and biases of science does not imply that other systems of knowledge are equally true, valid or efficient. After all, we may still hold on to a 'Popperian' belief that scientific knowledge is knowledge that may be discussed, criticised, modified, rejected, refuted and improved by its practitioners based on evidence and experiments (see e.g. Popper 1959 and 1969), and that such contributions may come from different cultures. In short, we may retain the idea that science, after all, describes a reality 'out there', although the notion of eternal and objective 'truth' has to be abandoned. (see also e.g. Ziman 2000). This position may be called a 'critical realist' position, and should not be taken to be a positivist stance.

A *critical realist position* may embrace an acceptance that science has cultural underpinnings, and this position opens for discussion of alternatives. It is also compatible with the prevailing constructivist approach that is so dominating in current thinking in science education. (A 'radical constructivist' position seems to go further in the direction of relativism.) A critical realist position also gives room for rather profound criticism of priorities and concerns in science – and even more so in the special version called *school science*. What a particular country or culture chooses to include in the science curriculum as worthwhile knowledge is certainly a highly subjective and value-laden decision. And although science as practised by the international research community *may* be seen as being universally accepted and without serious contenders, *school science* is certainly an area of heated debate – and it should always continue to be so! There is little reason to expect that school science should be more or less identical from one country to another, which unfortunately seems to be the case today.

There is a rich literature on feminist critique(s) of science (e.g. Harding 1986, 1991 and 1998, Keller and Longino, 1996). Unfortunately, most of this critique does not explicitly address the educational consequences of the different positions.

Different Reasons for Concerns about Gender

Many different groups of people are concerned about the low participation of girls and women in S&T. They have different reasons and different agendas and priorities. For analytical purposes, three stances can be identified.

1. Leaders in the industrial, technological and scientific establishment are concerned about low recruitment of qualified personnel with S&T qualifications. It is obvious that even academically gifted girls turn their backs on science and technology. The establishment becomes very interested in recruiting these gifted girls. This leads to recruitment campaigns and support programs of different sorts. Women already in the field of science and technology often engage in such campaigns. In many countries, the issue is put high on the political agenda, often with arguments and perspectives related to the job market and national competitiveness.

2. Other people are more concerned with power and equity in society. They note the low number of women in positions of high status, salary, and political and economic power. These people want to increase the proportion of women in such positions, and one of the most obvious is a job related to science and technology. Some who subscribe to this second stance go a little further in their social critique. They note that women in general are likely to have values and interests different from most men, and that women should have their voices heard inside the circles of power. These critics anticipate the possibility of changing priorities in politics, in the economy, and in the use of natural and human resources. This critical perspective from 'inside' science, however, does not challenge the basic assumptions about the nature of science itself.

A common factor in these two stances is that the underlying goal is to increase the participation of women in science and technology. Devotion to these common goal unities people from the two groups, although their underlying values, reasons, and motives may differ.

3.
The third stance goes much further in its criticism of science. People who embrace this third stance see science (and even more so, technology) as a male construction, which they describe by the following caricature: 'Science is concerned with controlling, dominating, and mastering nature. Science is a man-made activity in a literal sense, hierarchical, and based on a conception of nature where man stands outside nature instead of being part of it.' This view questions science in its present form, not only its use, but also its basic epistemological assumptions. Although there are variations in the degree of criticism of S&T, such positions are found in, for instance, Merchant 1989, Keller 1985, Harding and Hintikka 1983, Harding (1983, 1991, 1998). This critical approach draws upon different positions in the sociology of knowledge, and represents a serious challenge to the philosophy of science.

If one construes the gender and science issue in terms of the most *extreme* versions of the feminist critique, one would probably not encourage more girls into science and technology. Given the asserted male impregnation of the whole enterprise, one would rather persuade girls to reject this domain (and possibly to develop a different sort of science altogether?) In a context where we discuss the access of girls to science, this position is, in my opinion, rather counterproductive.

The important point to note about the three stances is the very wide range of people and interests involved in the issue of gender and science. We have to be aware of this range when we approach the literature in the field. It is also important to bear in mind that the issue of gender equity manifests itself very differently in different countries and cultures, and that care should be taken not over generalise or jump to unjustified conclusions.

Some observed differences between girls and boys

The research literature in science education proliferates in reporting girl/boy differences (see e.g. reviews like Kahle and Meece 1994, Rennie et al 1996). Data from the large comparative studies like TIMSS (1998) and PISA (2001a) are also reporting on gender differences. (For details and references to literature, see paper I.) One should, however, note that most of this research and documentation is based on studies in western, industrialized countries. In spite of large and very interesting cultural differences among countries (and among communities within a country), there remains some fairly commonly observed gender differences across cultures. Acknowledging the danger of oversimplifying, and keeping in mind the large within-group variations, the following gender differences are widely reported in the literature.

Interest in science declines with age (and with exposure to school science?) for both girls and boys, but more so for girls. (One should, however, note that this phenomenon is not confined to only science! Hence, one should take some care when drawing conclusions from such observations.) Also, biology is more popular among girls, chemistry is more neutral, and physics is the most problematic from a gender perspective. Physics seems to enjoy little popularity from both boys and girls, but less among girls. The observed differences between girls and boys increase with age.

Achievement in science follows a similar pattern. Boys as a group show higher scholastic achievement in physics. In chemistry the difference is smaller, but also favours the boys. In biology, however, the achievement pattern is more equal, with some parts of biology favouring girls. TIMSS and PISA report that these differences have become considerably smaller over the last decades. One should also note that the differences in favour of boys in science and mathematics achievement is considerably smaller that the difference in the favour of girls in reading and writing literacy!

Other gender differences of relevance for S&T teaching and learning are explored in the SAS-project (Science And Scientists). The box below is a short summary of findings of relevance for the gender issue. (Reported in Sjøberg 2000, 2002)

Science for the Children?
SAS-data on experiences, interests, priorities etc.

The SAS- project: 'Science And Scientists', is an investigation of interests, experiences and perceptions of children in many countries that might be of relevance for the learning of science and technology (S&T). The project involved some 30 researchers from 21 countries. Some 9 300 children at the age of 13 answered a questionnaire with closed and open-ended questions. The results are meant to be used for an informed debate over contents and priorities in the S&T curriculum and classroom teaching. Among the results are the following (For documentation, see Sjøberg 2002):

S&T-related Experiences

- Children in all countries have a wealth of experience that may be of relevance for the learning of S&T, but there are great variations between countries and between girls and boys.
- In all countries, boys have considerably more experience that is related to mechanics and electricity.
- Children in developed countries have more experience with (costly) new technologies. In these areas gender differences are rather small.
- Children in all countries have considerable experiences with household technologies (preservation and storage of food, knitting, sewing, making mats and baskets) – although the contents varies. Most activities are girl-dominated.
- Boys have somewhat more experience with S&T-related tools.
- Girls and boys have similar experience with reading scales and using measuring devices.
- Experiences with animals are male-dominated in developing counties, girl-dominated in developed countries.
- The use of guns and rifles is strongly boy-dominated, and with the Nordic countries on top.

S&T-related Interests

- Girls in all countries are more interested than boys in learning about health, nutrition and most aspects of biology.
- Girls and boys in all countries are interested in learning about earth science, the weather and natural phenomena.
- The difference in interests between girls and boys vary from topic to topic, but are generally largest in the Nordic countries and Japan.
- The most popular S&T items are often spectacular or relating to natural phenomena (life in the universe, extinction of dinosaurs, earthquakes and volcanoes).
- The interest in particular science content vary strongly with the context in which it is presented, and this may be a key to a gender fair S&T curriculum

Perceptions of Science and scientists

- Children in developing countries have a very positive image of scientists, and this expressed in a variety of ways.
- Many children in developed countries have a negative and stereotyped image of scientists. ('The crazy scientists')
- Children in all countries consider science to be useful for everyday life and for society – although children in developing countries are far more positive. Gender differences are small.
- Few children in developed countries seldom consider scientists to be kind or helpful – while this view prevails among children in developing countries.
- Very few children, in particular girls, consider science to be easy to learn.

Job priorities

- Girls in all countries are more person-oriented (helping people, working with people etc.) than boys.
- Boys in all countries are more ego-oriented (earn money, become famous etc.) than girls.
- Girls and boys have similar priorities related to 'self-

development' and 'time and job security'.

- Children in the Nordic countries are more gendered in their priorities than children from other parts of the world
- In developing countries, many children want to be scientists
- The popularity of possible areas for future work varies. The most popular is biology (for girls), earth science (for both) and technology (for boys). The least popular is physics.

Taken together, this kind of evidence lends credibility to the claim that if more women enter science and technology, then different priorities and concerns may be given voice. Credence is also given to the claim that STS-oriented science programs could help redress present gender inequities (For elaboration of this, see paper I).

John Head (1987) has reviewed research on personality traits and choice of careers (mostly in Western settings). His conclusion may seem rather provocative for most male scientists, be may be worthwhile quoting:

> Science is a conventional and acceptable career choice for boys; moreover, it appears to offer clear and firm answers. It is therefore attractive to a considerable number of immature boys who have not yet begun to question conventional wisdom and achieve their identity.
>
> Girls who do choose science are likely to be more emotionally mature, and to have considerable self-knowledge which support them in making unusual choices (Head, 1987)

Nature or Nurture? The Use or Misuse of Science

Why do we find the observed differences? How do we explain that girls and boys are so different in their approach to science and in their achievement and success in science? This brings us to the old question of Nature (biological inheritance, genes) versus Nurture (upbringing, education, learning, socialization). These two approaches to the problem differ on a fundamental level. The first seeks explanations in biology while the second looks for explanations in the social system.

Historically, the implicit point in the biologically oriented explanations for observed differences among people has been to explain those observed differences as 'natural,' for instance, the natural differences among races, among social classes, and, of interest to us in this paper, between women and men. The biological argument often leads to a rather deterministic position. Biology is interpreted as a restriction, thus providing justification for sexual determinism (Lambert 1978).

The history of gender debates offers an interesting perspective because the function of biological arguments has always been a defence of the status quo. Opponents to the status quo are invariably accused of wanting the 'unnatural' and wanting to 'change nature.'

Although the function of the biological argument remains the same throughout history, the form of that argument has constantly changed. When one form of biological argument is falsified by new scientific knowledge, new biological arguments are developed, always tailored to the present state of scientific understanding and always tailored to the particular social institution that needs to be legitimized. Of concern to us in this context is the case of the division of labour and social responsibilities between the sexes, and the differences in intellectual capacities and predispositions. In the 19^{th} century craniometry was a dominant line of research. Through measurements of the size and shape of human skulls one tried to explain differences between human races, between the sexes and also crime.

Scientists in the 1800s and early 1900s developed *craniology* (or *craniometry),* the measurement of head dimensions, in an attempt to document and to 'explain' differences among the races – and between men and women. Researchers proposed that each race had a particular head shape, measured as a ratio of the length to the width of the skull.

Similarly, *phrenology* – the study of the shape and size of the skull as a supposed indication of character and mental faculties – found popularity during the 19th century. A key conclusion in craniometry and phrenology was a 'ranking' of races as well as a ranking of the sexes. Not unexpectedly, white males came out on top. It should be no surprise that these approaches lost credibility after World War II....

Present forms of the biological argument cater to neuro-physiology, brain asymmetry, and visual-spatial abilities, to name but a few. There are, as with craniometry, historical reasons to be very cautious about biological deterministic arguments that support a certain ideology (Gould 1997).

What we do know, however, is that education and culture does play a large role in socialization and to gendered behaviour. The striking differences between what girls and boys 'naturally' are good at in different cultures should convince us. Educational and occupational statistics also shows large and interesting variations between countries. One should also keep in mind that comparisons of statistics focuses on averages, not on individuals! In any case, one should focus on the aspects that we, as educators, can do something about, and we know that this is a lot. (Then we may return in some hundred years to see if there still remains something to be explained!

The Nordic Scene as a Paradox

Gender equity has come relatively far in the Nordic countries (Norway, Sweden, Denmark, Finland and Iceland). On the previously mentioned UNDPs *Gender Empowerment Measure*, Norway is no 1, Iceland no 2, Sweden no 3, Finland no 4 and Denmark no 12 (UNDP 2001) Gender equity has been high on the political agenda for at least the last two decades, pushed forward by well-organized women's groups across the political spectrum. Most *formal* obstacles to gender equity have been removed. There is strict legislation against sex discrimination. Women's participation in the labour force is today only marginally different from that of men, and women have increased their participation in many sectors of society. For example, the representation of women in the Nordic parliaments as well as the Nordic governments is around 40%. At the top levels in banks and industry, however, the percentage of women is still very low.

In the education sector, gender equity has been a key element in reform and action. (In Norway, for example, school textbooks had, until 2001, to pass a test on sex discrimination before being officially approved.) In many ways, results are encouraging. At he turn of the century, about 55% of the graduates from the academic branch of upper secondary school were girls, and women comprised a majority (some 56%)

of the total number of students in tertiary education in all Nordic countries.

But there is a paradox: Statistics show that the female participation in science and engineering is lower than in many other countries where gender equity does not enjoy the same priority in political life. The situation is even worse: After experiencing a steady increase of women in science and engineering for some years, this positive development now seems to have stagnated or even reversed in the Nordic countries. In spite of women gaining numerical advantage in tertiary education, we are now observing a greater separation between men and women in their career choices. We observe that girls who actually perform very well in science, deliberately choose not to pursue science careers. Not because they are stopped from doing so, but as a result of a personal choice. This is an example where explanations are to be found on the subject-specific arena and not in a general sphere of gender discrimination. We have to address issues like the science curriculum and the open or hidden messages about science and technology conveyed through schools as well as through the media.

The Image of Science and Scientists

Young people's education and career choices are strongly influenced by affective factors such as their values and beliefs. Science, like other school subjects, carries both overt and covert messages about the nature of science and its practitioners. The public media constitute another source of messages. No matter what the source of images and stereotypes, it is useful to look at how science and scientists are perceived by children and adolescents in the context of gender differences.

Our own Norwegian results (Sjøberg and Imsen, 1988) seem to be consistent with most other findings in Western industrialized societies, so I shall use the Norwegian results as an example. Most scientists are seen to have the following traits: logical, intelligent, hard-working, and accurate. For other traits, students tend to distinguish between two groups of scientists: physical scientists or engineers on the one hand, and biologists or medical doctors on the other. The biologist is seen as 'caring,' the physicist as 'selfish.' The biologist is seen as 'open,' the physicist as 'closed.' Furthermore, the physicist is seen as boring and non-artistic, while the perception of the biologist is more neutral on these traits.

Other research results portray the typical scientist as male with traits similar to the 'mad-scientist' cartoon or movie caricature, who is absent minded and deeply entrenched in his own strange world, sealed off from the real world as life passes him by. It is interesting to note that both girls and boys tend to share these stereotypical images. They develop at an early age, and only become more refined and elaborated as the child grows older.

These images constitute a real challenge to science educators and to society as well, because they have a tendency to become self-fulfilling as the images influence occupational recruitment patterns. We know that girls tend to be more concerned about the personal and affective sides of their career choices, and that these values and priorities are in conflict with the caricature image described above. For boys, the contrast between their own values and those of the perceived scientist is not as great. As reported above, boys tend to be more pragmatic or instrumental in their career choices. Hence, boys may choose science in spite of some incongruence with their own values, because boys know that the job market is good and that studying science likely leads to safe jobs with higher earnings. Our own research in Norway shows that both women and men recruited into technical universities are much less person-oriented than their counterparts choosing other fields, and that the difference between women and men *within* this 'technical group' is just as large as within the other groups (Sjøberg and Imsen, 1988).

These affective aspects of career choice may be a key to understanding the seemingly paradoxical situation in Norway of low female participation in science and technology on the one hand, and higher participation in tertiary education by females on the other.

Relatively few studies of this kind have been performed in developing countries or non-Western cultures. A PhD study in Korea (Kim 1994) utilized the same instrument on the image of scientists that we used in Norway, and came out with some very interesting findings. She found that in Singapore as well as in South-Korea, the image of the scientist in some respects were similar to the Norwegian results; scientists were perceived to be intelligent, hardworking, accurate. They differed from the

Norwegian results on the more empathy-oriented traits: scientists were also perceived to be warm, helpful, oriented towards other people etc. In other words: The image of the typical scientist in countries with rapidly growing economies, like Korea and Singapore, is that they have positive traits both on the intellectual and the more human side. An expected consequence of this is that science may appear to be attractive for a much wider audience than it seems to be at present in the North.

These results are in line with what we observed in the SAS-study, described above, where children in the developing countries (among them some eight African countries) through drawings and writing presented the scientists as heroes and helpers. They are depicted as working to the benefit of society, lifting everybody towards a brighter future. This is a striking contrast to drawings in many Northern societies. In an open-ended question, pupils are invited to write a few words about what they would like to do if they had a chance to be a scientist. The same pattern is revealed here; many pupils would like to utilize their fantasy to improve other people's life and health. And, although the data from open writing are not analysed in detail, the gender difference is striking: girls are much more oriented towards these common and social goals than boys seem to be. Girls want to improve the life of their peers and fellow citizens, boys want to do things that are of interest and meaning to themselves. Very often, boys want to invent fantastic machines, travel in space or just work with cars and engines. (More details in Sjøberg 2002.)

Addressing the issue: No universally valid medicine!

The issue of girls in science education has to be placed in a wider context, and there is a danger that studies that are specific to one particular culture or educational setting is thought to be universal and general.

Let us take one example: The issue of single-sex vs mixed education (in classes, schools or even universities). Some studies conclude by recommending single-sex schooling. Great care should be taken when interpreting such findings, and benefits should be carefully balanced with negative effects. In countries where discrimination is strong (like in some African countries?) it may be a good policy to give the girls a chance to develop academically in more shielded milieus where they can avoid discriminatory practices from male pupils or even teachers, sometimes even sexual harassment. In other cultures, a strategy of separating girls and boys runs counter to other important educational and political aims.

Arguments for or against boarding schools should be interpreted in similar ways: In some countries, boarding schools may be a way to protect girls, liberate them from overburdened daily household chores and duties, and enhance their progress in the school system. In other cultures, 'the same' practice may me counterproductive, and in some countries, boarding schools are often private schools catering for the upper classes.

Hence, it is likely that the problems of gender and science education manifest itself very different in different cultures. Research results or strategies for action should therefore not uncritically be transferred from one context to another.

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(Placed at the end of this volume)

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