



Science Education in Europe: Critical Reflections

A Report to the Nuffield Foundation

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This report is based on two seminars held in London in 2006 at the Nuffield Foundation with contributions from the following individuals

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The views expressed in this document are those of the authors who have been advised by the group both in their presentations for the seminars and through their comments on drafts. Thus, we would like to acknowledge and thank them all for their contribution to this document.

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Foreword

Why study science? To quote the authors of this report: *“Science is an important component of our European cultural heritage. It provides the most important explanations we have of the material world. In addition, some understanding of the practices and processes of science is essential to engage with many of the issues confronting contemporary society.”* Yet in recent times fewer young people seem to be interested in science and technical subjects. Why is this? Does the problem lie in wider socio-cultural changes, and the ways in which young people in developed countries now live and wish to shape their lives? Or is it due to failings within science education itself?

In order to explore these questions the Nuffield Foundation convened two seminars involving science educators from nine European countries. The seminars investigated the extent to which the issues were common across Europe, the similarities and differences between countries, and some attempted solutions and remedies.

This report is based on those seminars. Its message is clear. There are shortcomings in curriculum, pedagogy and assessment, but the deeper problem is one of fundamental purpose. School science education, the authors argue, has never provided a satisfactory education for the majority. Now the evidence is that it is failing in its original purpose, to provide a route into science for future scientists. The challenge therefore, is to re-imagine science education: to consider how it can be made fit for the modern world and how it can meet the needs of all students; those who will go on to work in scientific and technical subjects, and those who will not. The report suggests how this re-imagining might be achieved. The recommendations are important and timely and deserve careful consideration by educators, policy makers and scientists alike.

The Foundation is grateful to the authors of the report, Jonathan Osborne and Justin Dillon, to Robin Millar for his thoughtful contributions to the planning and implementation of the seminars, and to all those who attended. We will be developing our own work and ideas in the coming months and years, and would be delighted to hear from other organisations, inside and outside the UK, with whom we might make common cause.

Anthony Tomei
Director
November 2007

Executive Summary

In the past two decades, a consensus has emerged that science should be a compulsory school subject. However, whilst there is agreement that an education in science is important for all school students, there has been little debate about its nature and structure. Rather, curricula have simply evolved from pre-existing forms. Predominantly these curricula have been determined by scientists who perceive school science as a basic preparation for a science degree – in short a route into science. Such curricula focus on the foundational knowledge of the three sciences – biology, chemistry and physics. However, our contention is that such an education does not meet the needs of the majority of students who require a broad overview of the major ideas that science offers, how it produces reliable knowledge and the limits to certainty. Second, both the content and pedagogy associated with such curricula are increasingly failing to engage young people with the further study of science. Indeed, there is a strong negative correlation between students' interest in science and their achievement in science tests.

Much of the current concern about science education, expressed in reports such as *Europe Needs More Scientists*^[1], concentrates solely on the supply of future scientists and engineers and rarely examines the demand. There is, for instance, a failure to recognise that science is a global activity where the evidence would suggest that there is no overall shortage at the doctoral level^[2] although there may be local shortages of particular types of scientists and engineers, for example, pharmacologists in the UK. There may also be shortages at the technician and intermediate levels of scientific and technological work but better data is needed before making major policy decisions on science education. In such a context, encouraging or persuading young people to pursue careers in science without the evidence of demand would be morally questionable. In addition, transforming young people's attitudes to science is a long-term project. Even if it could be achieved readily,

it would be at least a decade before any notable change in the supply would be noticed. Rather, the normative economic means of manipulating supply is through adjusting the financial remuneration offered to individuals.

The problem with framing the discussion about school science in terms of the supply of the next generation of scientists is that it defines the primary goal of science education as a pipeline, albeit leaky. In so doing, it places a responsibility on school science education that no other curriculum subject shares. Our view is that a science education *for all* can only be justified if it offers something of universal value for *all* rather than the *minority* who will become future scientists. For these reasons, the goal of science education must be, first and foremost, to offer an education that develops students' understanding both of the canon of scientific knowledge and of how science functions. In short that school science offers an *education in science* and not a form of pre-professional training.

Most school science curricula do attempt to serve two goals – that of preparing a minority of students to be the next generation of scientists – and that of educating the majority in and about science, most of whom will follow non-scientific careers. For the future scientist, their education best begins with the fundamentals of the discipline. In this approach, only students who reach a relatively high level of education in science develop a sense of the explanatory coherence of science and its major ideas. Yet it is this latter understanding – good examples of which can be found in the better quality of popular science writing^[3] – that everyone requires. Asking the school science curriculum and teachers of science to achieve both of these goals simultaneously places school science in tension where neither goal is served successfully.

In addition, the standard school science education has consistently failed to develop anything other than a naïve understanding of the nature of science, commonly called

'how science works'. Today, many of the political and moral dilemmas confronting society are posed by the advance of science and technology and require a solution which, whilst rooted in science and technology, involve a combination of the assessment of risk and uncertainty, a consideration of the economic benefits and values, and some understanding of both the strengths and limits of science. The current debate about how the challenge of global warming should be addressed is one example. Is it amenable to a technological solution or will it simply require humanity to adapt to the inevitable changes through measures such as better flood defences, improved water conservation and changes in agricultural land use? To understand the role of science in such deliberations, all students, including future scientists, need to be educated to be critical consumers of scientific knowledge. Improving the public's ability to engage with such socio-scientific issues requires, therefore, not only a knowledge of the content of science but also a knowledge of 'how science works' – an element which should be an essential component of any school science curriculum.

Recommendation 1

The primary goal of science education across the EU should be to educate students both about the major explanations of the material world that science offers and about the way science works. Science courses whose basic aim is to provide a foundational education for future scientists and engineers should be optional.

Traditional curricula in school science suffer from a number of difficulties. Knowledge is usually presented in fragmented concepts where the overarching coherence is not even glimpsed let alone grasped – an experience which has been described as akin to being on a train with blacked-out windows – you know you are going somewhere but only the train driver knows where. In addition, there is a growing gulf between the focus of school science – commonly the achievements of the 19th and early 20th Centuries – and the science that is reported in the media, such as astrophysics, neuroscience and molecular genetics.

Moreover, there still remains an enduring problem with the proportion of girls entering physical sciences and engineering in many but not all EU countries. Research has shown that there is a significant disparity between the aspects of science that interest girls and those that interest boys inviting the question as to what extent extant curricula serve the interests of girls?

Recommendation 2

More attempts at innovative curricula and ways of organising the teaching of science that address the issue of low student motivation are required. These innovations need to be evaluated. In particular, a physical science curriculum that specifically focuses on developing an understanding of science in contexts that are known to interest girls should be developed and trialled within the EU.

The issue of why school science is not as engaging for young people as other subjects is complex. Nevertheless, two factors would seem important. Students now live in a culture which is increasingly reflexive and one, in addition, in which they are confronted with a much wider range of subject choice than was the case in the past. Adolescence is a period of identity formation and there is good evidence that a critical issue for young people is how their subject choice frames their sense of self-identity – in particular, how it reflects their personal values. School science has done little to consider how it might appeal to the values and ideals of contemporary youth and their culture. Hence, our view is that what school science requires is a new vision of why an education in science matters that is widely shared by teachers, schools and society. In particular, it needs to offer a better idea of what kinds of careers science affords – both *in* science and *from* science – and why these careers are valuable, worthwhile and rewarding.

Recommendation 3

EU countries need to invest in improving the human and physical resources available to schools for informing students, both about careers *in* science – where the emphasis should be on why working in science is an important cultural and humanitarian activity – and careers *from* science where the emphasis should be on the extensive range of potential careers that the study of science affords.

A growing body of recent research has shown that most students develop their interest in and attitudes towards school science before the age of 14. Therefore, much greater effort should be invested in ensuring that the quality of science education before this age is of the highest standard and that the opportunities to engage with science, both in and out of school, are varied and stimulating. Within schools, research has shown that the major determinant of student interest is the quality of the teaching.

Recommendation 4

EU countries should ensure that:

- teachers of science of the highest quality are provided for students in primary and lower secondary school;
- the emphasis in science education before 14 should be on engaging students with science and scientific phenomena. Evidence suggests that this is best achieved through opportunities for extended investigative work and ‘hands-on’ experimentation and not through a stress on the acquisition of canonical concepts.

An accumulating body of research shows that the pedagogy in school science is one that is dominated by a conduit metaphor, where knowledge is seen as a commodity to be transmitted. For instance, teachers will speak of trying to ‘get across’ ideas or that students ‘didn’t get it.’ In this mode, writing in school science rarely transcends the copying of information from the board to the students’ notebook. It is rare, for instance, to see any collaborative writing or work that involves the construction of an argument. Even experiments are written up formulaically. Little opportunity is provided for students to use the language of science even though there is good evidence that such opportunities lead to enhanced conceptual understanding. Research would suggest that this limited range of pedagogy is one reason why students disengage with science – particularly girls. The recent report produced by a team for the EU Directorate General on Research, Science, Economy and Society¹⁴ argued that a ‘reversal of school science-teaching pedagogy from mainly deductive to inquiry-based methods’ was more likely to increase ‘children’s and students’ interest and attainment levels while at the same time stimulating teacher motivation’ – a view with which we concur.

Research would also suggest that deep, as opposed to superficial understanding, comes through knowing not only why the right answer is right but also through knowing why the wrong answer is wrong. Such learning requires space to discuss, to think critically and to consider others’ views. Contemporary school science education offers little opportunity for such an approach.

Recommendation 5

Developing and extending the ways in which science is taught is essential for improving student engagement. Transforming teacher practice across the EU is a long-term project and will require significant and sustained investment in continuous professional development.

Any learning experience is framed by three aspects – curriculum, pedagogy and assessment. For too long, assessment has received minimal attention. Tests are dominated by questions that require recall – a relatively undemanding cognitive task and, in addition, often have limited validity and reliability. Yet, in many countries, the results of a range of tests, both national and international, are regarded as valid and reliable measures of the effectiveness of school science education. Teachers naturally, therefore, teach to the test, restricting and fragmenting the content and using a limited pedagogy. Transforming this situation requires the development of assessment items that are more challenging; cover a wider range of skills and competencies; and make use of a greater variety of approaches – in particular, diagnostic and formative assessment.

Recommendation 6

EU governments should invest significantly in research and development in assessment in science education. The aim should be to develop items and methods that assess the skills, knowledge and competencies expected of a scientifically literate citizen.

The major determinant of any education system is the quality of its teachers. Teachers who are knowledgeable and effective communicators are able to engage their students in substantive conversations, ask searching questions and have a deep understanding of their own subject. There is considerable evidence that recruiting teachers of science of the highest quality in many countries is either problematic, or is likely to become problematic in the coming decade. In addition, it is very important to invest in, and retain, good teachers who are already working in our schools.

Recommendation 7

Good quality teachers, with up-to-date knowledge and skills, are the foundation of any system of formal science education. Systems to ensure the recruitment, retention and continuous professional training of such individuals must be a policy priority in Europe.

Introduction

Science education in Europe has recently been the focus of considerable attention. The predominant factor behind this interest is the declining numbers of young people choosing to pursue the study of science^[1] and the threat this poses to the Lisbon agenda which seeks to place the EU at the forefront of the knowledge economy of the future. The idea behind these two Nuffield-funded London seminars was to draw together a group of leading science educators, from across Europe, to consider the state of science education in the EU. Invitations were extended to those engaged in science education, albeit principally academic science educators, from a range of European countries that were felt to represent the diversity of countries within the EU. The first seminar was held in London, at the Nuffield Foundation headquarters, on June 1-2, 2006 and the second was held, in the same year, on December 7-8. In addition, an initial draft of the main findings of the report was presented and discussed at the biennial conference of the European Science Education Research Association held in Malmö, Sweden in August, 2007.

The focus of the first seminar was very much on exploring the current state of science education across Europe, the issues that are confronting it, and the evidence for those views. The seminars sought to explore what were felt to be the four key issues that are central to the nature of the teaching and learning experience offered by school science. That is:

- Curriculum
- Pedagogy
- Assessment
- Teacher supply, professional development and retention

Discussion of each of these areas was initiated by short presentations of the issues confronting two countries that served as contrasting examples. These discussions focussed on three questions:

- What are the major issues confronting formal secondary science education?
- What evidence is there?
- Is the situation common throughout Europe or is there variation?

A major characteristic that emerged immediately is that there is no commonality within Europe, confirming a feature which is shown in more detail in the Eurydyce report on Science Teaching in Europe^[6]. Rather, what Europe has is a distribution around a mean. For instance, in Poland and Spain there is little difficulty in recruiting science teachers, whilst in England, the opposite is true. Likewise, whilst some countries have curricula that offer more integrated science curricula, others are still strongly rooted in the separate sciences.

The one area, however, in which there is a common trend is in the decline of student attitudes to science. We were presented with data from the ROSE^[6] project which shows that there is a 0.92 negative correlation between students' attitude towards school science and the UN index of Human Development. Thus Norway, which is top of this index, has the worst student attitudes to science. That there is such a clear trend would suggest that this is a feature that is systemic to the nature of advanced societies and not to schools or the teaching of science. Nevertheless, in our discussions, reported below, there are aspects of contemporary practice in the teaching of school science that contribute to this relationship. The major issues emerging from the group's discussions in both seminars and our recommendations are provided in what follows.

Findings and Recommendations

Part 1: The State of Science Education in Europe

1. Many countries are experiencing significant problems with engaging students with the advanced study of physical sciences. Where this is the case, it is a source of significant concern. However, this pattern is not universal across Europe and appears to be strongly correlated with the level of economic advancement in any given country.

1.1. Many countries have seen declining numbers of students choosing to pursue the study of physical sciences, engineering and mathematics at university. For instance, from 1993-2003 the percentage of S&T graduates has fallen in Poland, Portugal and France. The same is true in Germany and the Netherlands^[7]. In addition, the percentage of graduates studying for a PhD – the most common route to becoming a professional scientist – has dropped in all European countries. The consequence is that the supply of scientists to sustain knowledge economies, which are heavily dependent on science and technology, is perceived as a significant problem. This predicament was addressed in a major report – *Europe Needs More Scientists*^[1] – which laid out a series of recommendations to address the issue.

1.2. The ROSE study of students' attitudes to science in more than 20 countries has found that students' response to the statement 'I like school science better than other subjects' is increasingly negative the more developed the country (Fig. 1). Indeed, there is a 0.92 negative correlation between responses to this question and the UN Index of Human Development^[6]. In short, the more advanced a country is, the less its young people are interested in the study of science.

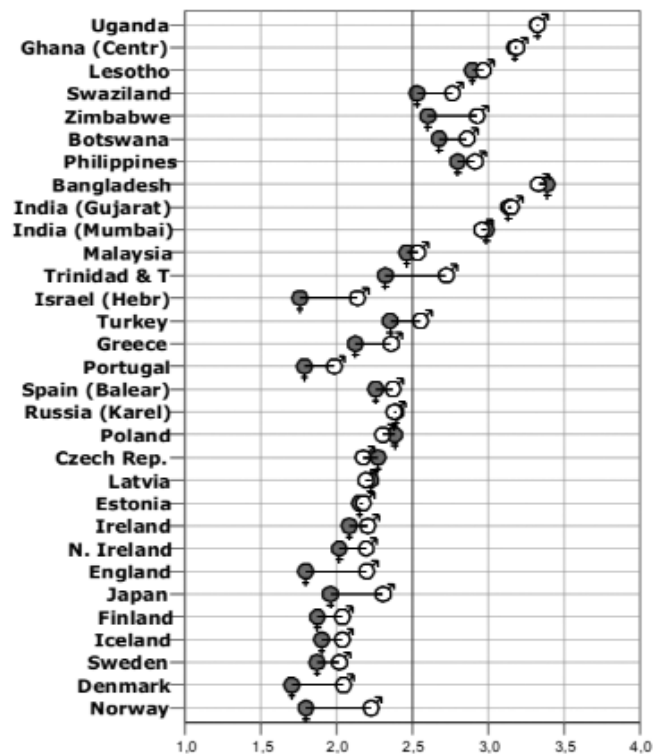


Fig. 1: Data from the ROSE study^[6] showing students responses to the question 'I like school science better than most other school subjects' (1 – strongly disagree, 4 – strongly agree; dark symbols – female/light – male)

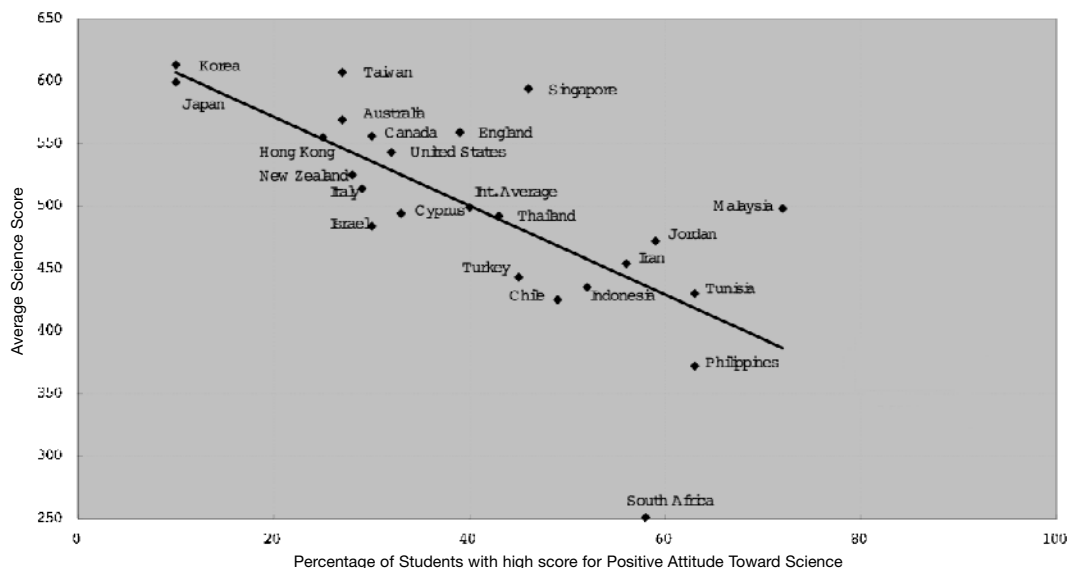


Fig 2: Relationship between student achievement and student attitudes to science for TIMSS data^[9]

1.3. Likewise, an analysis of the data from the Third International Mathematics and Science Study (TIMSS), conducted in 1999, and which measured both student attainment and student attitude towards science, shows that the higher the average student achievement, the less positive is their attitude towards science (Fig. 2 above).

1.4. One interpretation of these data sets is that this is a phenomenon that is deeply cultural and that the problem lies beyond science education itself. Given that learning science is demanding, that it requires application, discipline and delayed gratification – all values which contemporary culture might be said to neglect – there may be some substance to this view. In addition, the immediate relevance of the subject may not be evident to students.

1.5. In the context of the EU there is, however, less of a recruitment problem in Southern and Eastern Europe, raising the question of whether there is a problem or whether it is simply a mismatch between supply and demand. However, data presented in the EU report *Europe Needs More Scientists*^[1] show that the number of researchers across the EU is 5.7 per 1000 of the workforce whilst the comparable figures for Japan and the USA are 9.14 and 8.08 respectively, suggesting that the problem has a pan-European dimension. Moreover, if students' attitudes towards school science remain as negative as they are currently, the issue of the supply of scientists, and whether Europe is producing sufficient, will be exacerbated and not diminished.

1.6. Nevertheless, much of the concern is focussed around the issue of supply and fails to recognise that science operates in a global context. Here the evidence would suggest that, at a global level, there is

no shortage of doctoral scientists^[9]. For instance, evidence from the US context^[2] shows that there is an oversupply of students with biomedical PhDs and, as a consequence, the success rate on applications to the National Institute of Health, the government agency responsible for funding research, has declined from 26% to 19% from 2000 to 2005. Likewise unemployment in science and engineering professions in the US follows the overall rate and is not markedly lower. If there is no substantive demand for scientists overall then increasing supply without increasing demand is, at best, unwise and wasteful and, at worst, morally questionable.

1.7. Indeed, whilst there may be particular local shortages, it is difficult to escape the conclusion that much of the concern is born of a nationalistic hubris that is perturbed by its failure to sustain the competitiveness of its traditional industries through the home-grown production of scientists. In a 'flat' world, however, we would argue that it is inevitable that the competitors to Europe – mainly the Asian economies – will catch up or even surpass the achievements of European science. Concerns about the future supply of scientists are often stoked by the scientific community who have much to gain from persuading governments to invest in research, development and training in science and technology^[2, 10]. In the UK, similar alarm was expressed in the Dainton report^[11] published in 1968 and the UK economy has survived the doom-laden scenarios painted in that report well. As some US scientists have aptly argued 'Time after time we have been warned of impending shortages which, with evergreen consistency, are subsequently transformed into gluts to the dismay of those most affected: the future practitioners of our discipline.'^[10]

- 1.8. Moreover, attempting to adjust the supply by improvements to science education is a long-term solution where positive effects are unlikely to be achieved within a decade. Classical economic theory tells us that supply and demand are best kept in balance through adjusting the payments made to suppliers – in this case individuals with scientific and technological expertise. To date, there is little evidence that the shortfall has had that effect. Rather universities and industry have acknowledged that local shortages can be addressed by filling posts from the global supply.
- 1.9. Another consequence of the focus of the debate on the future supply of scientists and engineers is that it portrays the principal role of the school science curriculum as a means of delivering the human resources necessary to sustain the competitive edge of European economies. Nowhere is this more evident than in the recent UK report *The Race to the Top: A Review of Government's Science and Innovation Policies*^[12] – both in its title and when it argues that ‘the pipeline of STEM students is a concern’. Notably absent is any recognition that there might be other purposes for science education. In contrast, we would strongly concur with the view articulated in the report *Europe Needs More Scientists* that ‘SET subjects at the compulsory level cannot and should not be seen primarily as the first stage in the recruitment of the SET workforce. The job and career prospects should not be the prime concern of any subject at this stage.’
- 1.10. Rather, at the heart of many European conceptions of education is the liberal notion that it should serve the purpose of offering young people the best that is worth knowing. In many Northern European countries there is a somewhat more complex notion of *bildung* which is that education should develop the full potential of the individual. In short, our view is that the primary goal of including science in the school curriculum is because it is an important component of our European cultural heritage which provides the most important explanations we have of the material world. In addition, some understanding of the practices and processes of science is essential to engage with many of the issues confronting contemporary society.

2. Whilst science and technology are often seen as interesting to young adolescents, such interest is not reflected in students’ engagement with school science that fails to appeal to too many students. Girls, in particular, are less interested in school science and only a minority of girls pursue careers in physical science and engineering. The reasons for this state of affairs are complex but need to be addressed.

- 2.1. Rather than asking how can we get more young people to pursue science, the first question that any country must ask is whether school science is failing to communicate why a knowledge *of* science and a knowledge *about* science are both hard won and valuable in contemporary society and, if so, how can that failure be addressed?
- 2.2. Answers to the question about how we can engage young people with school science are complex but research and scholarship would suggest that the lack of engagement is a mix of:
- A lack of perceived relevance. School science is often presented as a set of stepping-stones across the scientific landscape and lacks sufficient exemplars that illustrate the application of science to the contemporary world that surrounds the young person. An oft-quoted example is the inclusion in science lessons of the blast furnace and the Haber process, both of which do not relate easily to what has been christened the ‘iPod generation’.
 - The failure to generate a sense of anticipation that accompanies an unfolding narrative. That is, rather than beginning with what might be called overarching questions, such as ‘Why do you look like your parents?’ or ‘What does the universe consist of?’ and then attempting to describe elements both of what we know and how we know, school science begins with foundational knowledge – what a cell consists of, the elements of the Solar System, or the laws of motion – ideas which appear to most children as a miscellany of unrelated facts. The bigger picture only unfolds for those who stay the course to the end. Lacking a vision of the goal, however, the result is akin to being on a journey on ‘a train with blacked-out windows, you know you are going somewhere but only the train driver knows where.’^[13]
 - A pedagogy that lacks variety.
 - A less engaging quality of teaching in comparison to other school subjects^[14].
 - Content which is too male-orientated^[15].
 - An assessment system that encourages rote and performance learning rather than mastery learning for understanding. Some countries, notably the UK, have introduced systems of assessment that, whilst designed to assess the performance of the student, have become, indirectly, a measure of the performance of the teacher and the school. Such assessment is ‘high stakes’ and results in a

Recommendation 1

The primary goal of science education across the EU should be to educate students both about the major explanations of the material world that science offers and about the way science works. Science courses whose basic aim is to provide a foundational education for future scientists and engineers should be optional.

| Boys | Girls |
|--|---|
| <p>Explosive chemicals</p> <p>How it feels to be weightless in space</p> <p>How the atom bomb functions;</p> <p>Biological and chemical weapons and what they do to the human body;</p> <p>Black holes, supernovae and other spectacular objects in outer space.</p> | <p>Why we dream when we are sleeping and what the dreams might mean</p> <p>Cancer – what we know and how we can treat it</p> <p>How to perform first aid and use basic medical equipment;</p> <p>How to exercise the body to keep fit and strong;</p> <p>Sexually transmitted diseases and how to be protected against them</p> |

Table 1: The top 5 items boys would like to learn about in science and the top 5 for girls

pedagogy where breadth and repetition are emphasized at the expense of depth and variety. Evidence exists that even at a young age this form of assessment has a negative effect on student engagement^[16].

- 2.3. Moreover, despite nearly 30 years of efforts to engage girls in physical sciences and engineering, girls still remain in a minority. Percentages of female maths, science and technology graduates vary from 19.5% in the Netherlands to a maximum of 42% in Bulgaria, with an average of 31% across Europe^[17]. Whilst there is still some debate about whether such differences are innate or cultural, there is a high level of concern that both girls *and* science are losing out. Girls, because their lack of engagement with the further study of science forecloses a number of career options, and science because it is failing to attract a large number of students who potentially have a very significant contribution to make.
- 2.4. The reasons for the lack of girls' engagement with the physical sciences, engineering and mathematics are complex^[15]. Students' choices of subjects are influenced by an intricate mix of parental aspirations, by their sense of their own ability, by the quality of the teaching (which affects their view of the subject), and by their sense of identity which, for most students, is strongly gender-related.
- 2.5. In the case of the curriculum itself, some insight into the nature of the problem comes from a detailed analysis of the English ROSE data^[18]. The ROSE questionnaire presents 108 topics that students might like to learn and asks its respondents to rate them on a scale of 1 ('not at all') to 4 ('very interested'). Between English boys and girls there were 80 statistically significant differences. The top five items for English boys and girls are shown in Table 1.

- 2.6. Such a stark contrast invites the question of whose agenda – boys or girls – is best served by the extant curricula? For instance, research would suggest physics content interesting to girls is almost always interesting to boys but the reverse is not necessarily true and, moreover, that the content of interest to girls is 'by far underrepresented in the curriculum'.^[19] These data are also supported by other research which would suggest that girls would be interested in a physics curriculum which had more human related content^[20]. To date, we are not aware of any substantial curricular initiatives that have explicitly set out with the primary focus of engaging the interests of girls. Such an initiative is now long overdue in the light of the failure of numerous other innovations to have any substantive effect.

Recommendation 2

More attempts at innovative curricula and ways of organising the teaching of science that address the issue of low student motivation are required. These innovations need to be evaluated. In particular, a physical science curriculum that specifically focuses on developing an understanding of science in contexts that are known to interest girls should be developed and trialled within the EU.

3. Recent research suggests that there are distinct groups of students who respond to science in very different ways. Gender is a significant factor in these differences. If more young people are to engage with science, it is important that science educators both know of, and respond to, these differences and that school science offers a vision of why careers both *in* and *from* science are a means of achieving self-fulfillment.

3.1. The group were presented with a factor analysis of the student responses to the ROSE^[6] questionnaire from Norway. This analysis found five distinct groups of students who had different sets of values. These included a group, predominantly male, who were fascinated by technology, and, in contrast, a predominantly female group who wanted to work with others and develop themselves as people. This finding is similar to that of Haste^[21] who conducted a survey of the values and beliefs that 704, eleven to twenty-one year old individuals held about science and technology. She found that there were four types of individual:

- The 'Green' who held a set of ethical concerns about the environment and who were sceptical about interfering with nature. Members of this group were predominantly girls under 16 who would be interested in a job related to science.
- The 'Techno-investor' who was enthusiastic about investing in technology and the beneficial effect of science. Such individuals trusted both scientists and government and consisted of boys under 16 and young men over 16 in the workforce.
- The 'Science Orientated' who were interested in science and who held a belief that a 'scientific way of thinking' can be applied widely. This group was predominantly boys over 16 both in full-time education and in the workforce.
- The 'Alienated from Science' who found science boring and were sceptical of its potential. The group consisted predominantly of younger girls and young women over 16 in the workforce who were not interested in a job related to science.

3.2. An analysis presented by Schreiner and Sjøberg^[22], drawing on contemporary notions of identity, was found to be particularly insightful. Their contention, which fits with other research, is not that there is a lack of interest or respect for science and technology but rather that the perceived values associated with science and technology do not match the values of contemporary youth. For instance, late-modern society has seen a transformation of the perception of science as a source of solutions to a perception of science as a source of threat^[23]. In the European cultural context, as communications and access to travel have improved, there has been a dissolution in the role of traditional structures in establishing individuals' identities. Increasingly, we live in a society

where people have more autonomy and choice; routinely question standard practices; and where individuals actively construct their self-identity rather than accept what, in earlier times, was a pre-destined route determined by their social and economic context. Youth, likewise, share in this sense of freedom to choose their social groupings (which are now widely shared through Internet websites such as MySpace, Facebook & Twitter^[24]), their lifestyle, religion and values. In addition, contemporary societies value creativity and innovation more highly than might have been the case in the past.

3.3. In the context of school, young people define and communicate their identities through aspects such as their choice of clothing, subject preferences and behaviour. Moreover, adolescence is a particularly significant time when young people are first confronted by the need to construct their sense of self. As has been well-documented, this situation creates a state of insecurity or moratorium^[25]. In some senses, this angst is not new. All young people have had to undertake this process. What is new is that the range of choices presented to contemporary youth is now much greater. For instance, rather than a simple choice between studying the arts or sciences at school, students are now offered an ever-widening range of subjects which can be mixed in different combinations. The result is that subject choice has changed from an issue of being 'What do you want to *do* when you grow up?' to one of 'Who do you want to be when you grow up?' Education in such a context becomes a means of self-actualization and finding personal meaning – a value reflected in the contemporary obsession with celebrity. In such a context, personal interest becomes the dominant factor in subject choice not the possibility of any future career it affords. Hence, whilst science might be perceived as quite interesting, it is seen as 'not for me' by many young people as it is identified with becoming a scientist or engineer^[18, 26] – careers which are strongly associated with the advancement of technology rather than aiding people, and not as a means of self-realisation.

3.4. Our view is that these insights point to the need for a new sense of purpose for school science which must emphasise how working in science can be a means of self-fulfillment. Traditionally, school science has been presented as a source of technological solutions whose study had instrumental value in providing access to a set of STEM¹ – related careers. Why these careers might be of value to society or how they might assist humanity has rarely been an explicit focus of school science. Arguably, the compulsory nature of school science does not require teachers of science to offer a vision of why it matters, as there is no need to persuade students of the value of studying science. Indeed, the evidence would suggest that

¹ STEM is the term commonly used in the UK to refer to Science, Technology, Engineering and Mathematics. Since the seminars, it has become an increasing focus of the UK government policy agenda.

many teachers of science have a very limited conception of careers *in* science let alone of the possibilities of careers *from* science – that is careers which do not inherently require science qualifications but which science qualifications give access to, for example, careers in finance, management and law^[27].

- 3.5. The reality could hardly be more different. The five major problems facing humanity in the coming century, according to the UK Government's former Chief Scientific Advisor, are feeding the population, the control of disease, generating sufficient energy, supplying enough water, and global climate change. Each of these problems will only be solved, in part, by the enormous contribution that science and engineering must make – from producing more fuel-efficient forms of transport to developing higher-yielding crops that will grow in more marginal soil and climate conditions. If it is to meet the needs of the future, school science has to develop opportunities for students to explore what it is that scientists do and why that contribution is both enduring and meaningful. In addition, it needs to show that those who study science do not simply spend their lives working in one narrow domain. Rather, that the contrary is true – the study of science opens doors to a multitude of possibilities for self-realisation.
- 3.6 School science, therefore, must demonstrate that the study of science enables young people to pursue the widest range of careers possible and appeal to their aspirations. In particular, it should exemplify how working as a scientist can contribute to solving the problems faced by society, and show that the study of science is not simply a gateway to a scientific career but that there are as many careers *from* science as there are *in* science. In short, it must offer young people a new vision of why science matters.

Recommendation 3

EU countries need to invest in improving the human and physical resources available to schools for informing students, both about careers *in* science – where the emphasis should be on why working in science is an important cultural and humanitarian activity – and careers *from* science where the emphasis should be on the extensive range of potential careers that the study of science affords.

4. Student engagement or interest in science is largely formed by the age of 14. This situation has implications both for the formal curriculum and for opportunities to engage with science outside the classroom.

- 4.1. One of the questions emerging from the previous discussion is at what age is it best to attempt to engage young people with science? Traditionally, much effort has been expended at the point of subject choice when individuals' decisions can have life-changing implications. In England, for instance, there is an element of choice at 14 but the main choice is made at 16. Little attention has been paid to engaging children of a younger age. Yet, while student interest in science at age 10 has shown to be high, with no gender difference^[28], by age 14 it has declined markedly^[29]. Recent research would suggest that, for the majority of students, interest in pursuing further study of science has largely been formed by the time children are 14. For instance, in a recent analysis of data collected by the US National Educational Longitudinal Study, Tai et al.^[30] showed that the effect was such that, by age 14, students *with* expectations of science-related careers were 3.4 times more likely to gain a physical science and engineering degree than students *without* similar expectations. This effect was even more pronounced for those who demonstrated high ability in mathematics – 51% being likely to undertake a STEM-related degree. Indeed Tai et al's analysis shows that the average mathematics achiever at age 14, with a science-related career aspiration, has a greater chance of achieving a physical science/engineering degree than a high mathematics achiever with a non-science career aspiration (34% compared to 19%).
- 4.2. Further evidence that children's life-world experiences, prior to age 14, are the major determinant of any decision to pursue the study of science comes from a survey by the UK Royal Society^[31] of 1141 SET practitioners' reasons for pursuing scientific careers. A key finding was that just over a quarter of respondents (28%) first started thinking about a career in STEM before the age of 11, and a further third (35%) between the ages of 12-14. Likewise, a small-scale longitudinal study following 70 Swedish students from Grade 5 (age 12) to grade 9 (age 16)^[32], found that their career aspirations and interest in science were largely formed by age 13. Lindahl, the author of this study, concluded that engaging older children in science would become progressively harder^[32].

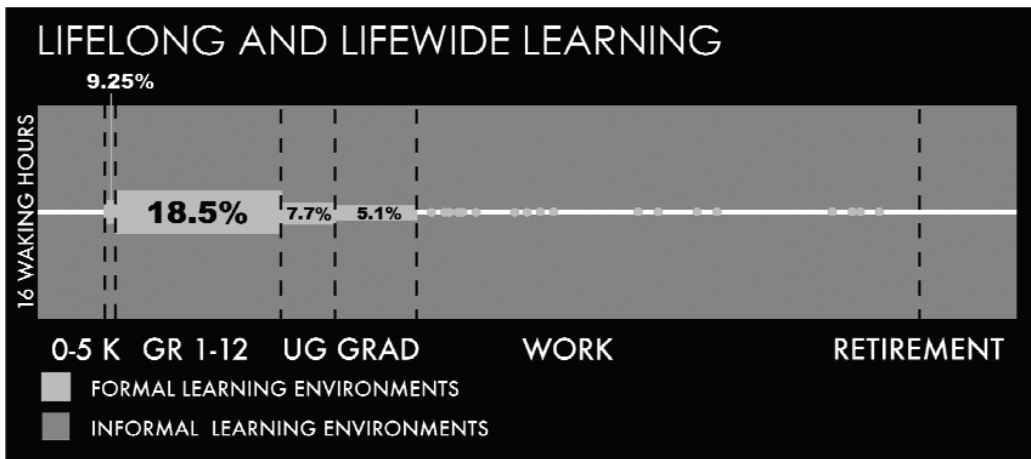


Fig. 3: Proportion of time spent in formal/informal learning environments (using American terminology) across an individual's life^[33]

- 4.3. Currently, we know little about the factors that lead children under the age of 14 to be interested in science or not. How much it is a factor of school or outside influences is, for instance, one critical issue. Some sense of the significance of experiences outside the classroom is demonstrated by Fig 3 which shows that time in school occupies only 18.5 per cent of a child's waking hours between the ages of 5 and 18 suggesting that what happens outside the classroom may be as important as what happens inside the classroom.
- 4.4. Taken together, these data strongly suggest that efforts should be expended to ensure that children's early encounters with science before the age of 14 should be as stimulating and engaging as possible. Some messages from the research for policy-makers and educators are relatively clear – the experience should:
- be rich in opportunities to manipulate and explore the material world;
 - use a pedagogy that is varied and not dependent on transmission;
 - offer some vision, however simplified, of what science offers both personally in satisfying material needs and as a means of realising an individual's creative potential;
 - be provided in both formal and informal contexts for learning. A single encounter with a science-based activity post-14 is unlikely to have a significant impact. What is required is a continuum of educational experiences of science from an early age.
- 4.5. In addition, rather than using the best teachers to teach only the more able, older students, such teachers need to be deployed to work with children under the age of 14 as well.

Recommendation 4

Countries should ensure that:

- teachers of science of the highest quality are provided for students in elementary and lower secondary school;
- the emphasis in science education before 14 should be on engagement. Evidence would suggest that this is best achieved through opportunities for extended investigative work, and 'hands-on' experimentation and not through a stress on the acquisition of canonical concepts.

Part 2: Improving School Science Education

The state of affairs in school science education portrayed in Part 1 is the consequence of many complex factors. In the seminar discussions, aspects of curriculum, pedagogy, assessment and teacher supply, professionalism and retention were identified as contributing factors within the context of school education. In what follows, we discuss each aspect separately. However, we are conscious that systematic improvement will only be achieved by attending to all four of these elements. Research^[34] would suggest that to attempt to improve one without the others is largely a wasted effort.

Curriculum

5. As we have argued in Part 1, there is a lack of a clear vision across Europe of the purpose and goal of formal science education. On the one hand, school science is essential to produce the next generation of scientists, engineers and doctors and, on the other hand, it is a dominant part of contemporary culture – a way of knowing about the material world of which all should have some rudimentary understanding. Evidence would suggest that it is the first of these goals that largely determines the nature of school science at the expense of a curriculum that might meet the needs of the majority.

5.1. Across Europe, the structure of the science curriculum varies, reflecting different and contested views of how school science should be organised. In most countries, biology, chemistry and physics are clearly distinguished – at least in secondary education. However, the degree of organisation and specificity of the curriculum varies widely. For example, in Spain the curriculum is divided into 9 or 10 units for each of the science subjects, whereas in England there are only 4 units for science as a whole and the words biology, chemistry and physics do not appear in the National Curriculum. Norway follows a relatively typical ‘academic’ pattern in which science is obligatory throughout grades 1–11, during which time it is taught as an integrated subject called ‘science’. In grades 12 and 13, students can choose to follow science lessons or not. At these grades students can decide if they want to study any of the following subjects: biology, chemistry, physics, geology and technology. When choosing to study science, it is common to choose a combination of

two of these subjects. Structural limitations in the students’ time schedule are such that only very few students choose three subjects. In Germany, the secondary curriculum clearly distinguishes the separate sciences and, even if science is taught in an integrated manner, it is usually as a succession of the separate subjects. Current movements for science curricula (in the different types of school: *Hauptschule*, *Realschule*, *Gymnasium* and – in the growing replacement of the three-tiered system *Gesamtschule*) aim to have a more integrated focus. So, if there is a trend, it is that school science is becoming more integrated across Europe, although the pace of change is relatively slow.

- 5.2. Nevertheless, what was apparent is that, with the exception of the new English curriculum *Twenty First Century Science*, all curricula are essentially similar in their nature commencing by introducing basic concepts that are then revisited in later years in more depth. Presented in this form, the experience for students is often one where:
- The science curriculum can appear as a ‘catalogue’ of discrete ideas, lacking coherence or relevance, with an over-emphasis on content that is often taught in isolation from the kinds of contexts that might provide essential relevance and meaning.
 - The goals and purpose of science education are neither transparent nor evident to students.
 - Assessment is based on exercises and tasks that rely heavily on rote memorisation and recall, and are quite unlike those contexts in which learners might wish to use science knowledge or skills in later life (such as understanding media reports or understanding the basis of personal decisions about health, diet, etc.).
 - The relationship between science and technology is neither well-developed nor sufficiently explored.
 - There is relatively little emphasis, within the science curriculum, on discussion or analysis of any of the scientific or environmental issues that permeate contemporary life.
 - There is an over-reliance on transmission as a form of pedagogy with excessive use of copying^[32, 35, 36].
- 5.3. A complementary goal of science education, however, is to educate students about science in order to provide them with the kind of understanding required of informed citizens. Whilst the achievements of

science offer us the best explanations of the material world we have, it is important to have some understanding, in addition, of how the ideas and understanding that science offers – few of which are self-evident – have been achieved. Such intellectual capital contributes to developing the educated person.

- 5.4. Contemporary scholarship^[37, 38] would suggest that such a goal is achieved by:
- developing an understanding of the major explanatory themes of science; showing the tremendous intellectual and creative achievement such ideas represent;
 - exploring the initially tentative nature of scientific knowledge claims and the ways in which these ideas are consensually agreed to generate reliable knowledge; and
 - exploring the implications of the application and use of scientific knowledge.
- 5.3. Such a curriculum – which serves the needs of developing a scientifically literate public – would be significantly different from that currently offered throughout most of Europe. It would recognise that, for the overwhelming majority, their experience of learning science in school will be an *end-in-itself* – a preparation for living in a society increasingly dominated by science and technology and not a preparation for future study. Its content and structure could then only be justified on this basis. It would represent an introduction to the cultural capital offered by science, its strengths and limitations, and develop an understanding, albeit rudimentary, of the nature of science itself. Our view is that *all* students, including future scientists, need this form of education at some stage of their school career.
- 5.4. However, the content of the science curriculum has largely been framed by scientists who see school science as a preparation for entry into university rather than as an education for all. No other curriculum subject serves such a strong dual mandate. The result for teachers is that they must work with the tension that exists between these twin goals – the needs of future scientists and the need of the future non-scientists. As we have argued earlier, different goals require different approaches..
- 5.5. The solution, we believe, is twofold. First, there needs to be greater clarity about these twin aims so that it is clear which goal is being served by any curriculum at any one time. Second, all countries need to offer, at some stage, a curriculum which is an education *about* science, its achievements and its practices to all students. Even for scientists, let alone the non-scientist, the current system results in teachers of science and scientists who have a limited understanding of their own subject^[39, 40]. In addition, courses which aim to prepare students for the further study of science should be optional –

something which students choose to do rather than being compelled.

- 5.6. One objection to this suggestion is that learning science is a linear hierarchy – performance in any stage being critically dependent on successful completion of the prior stage. Courses that failed to develop the detailed knowledge necessary to become a practising scientist would curtail students' opportunities. However, we would argue that to place this responsibility on school science is unacceptable both morally and economically. Morally, because the needs of a minority are imposed on the majority, and economically, because the accumulating evidence is that such an experience is increasingly alienating more and more students from science. Rather, we would suggest that it is essential to construct routes into science from alternative starting points to widen the base of potential recruits. In short, that there are multiple routes in science education to multiple differing outcomes.
- 6. There have been several attempts to engage students with school science by changing the curriculum. The outcomes of these innovations are, as yet, unclear.**
- 6.1. Across Europe there have been a number of notable attempts to enact a form of science education that, in one form or another, might achieve the goal of educating young people for citizenship in contemporary society. In the UK, these began with the development of an optional course called *Science for Public Understanding*^[41] for 17-18 year olds. From this, the University of York and the Nuffield Curriculum Centre developed a course for 14-16 year olds – *Twenty First Century Science* (www.21stcenturyscience.org) – which consists of three components. First, a core curriculum that explores both the major explanatory themes of science and a set of 'ideas-about-science' that all students do. This is then followed by an additional course of academic science which is for those who wish to pursue the study of science at a later stage. Alternatively, students with a more vocational inclination can take a course in Applied Science. One of the primary goals of the course has been to free school science from the twin mandate of simultaneously educating both the future scientist and the non-scientist.
- 6.2. In the Netherlands, a course was developed in the late 1990s called *Algemene Natuurwetenschappen* (General Natural Sciences) that is compulsory for all students in grade 10 (age 16/17) including those who had decided not to continue with the study of science. The course has been contentious and gone through some transformation since. The findings of the evaluation were that it was 'extremely difficult' for teachers 'to escape from the shadows of the science teaching tradition.'^[42] – that is their pedagogy was still dominated by a focus on content rather than

developing an understanding of science itself. A similar conclusion about the difficulties for teachers taking such an approach was found in other research^[43]. This is not surprising – the teaching of science is an established cultural practice passed on from one science teacher to another. Transforming what the body politic of science teachers considers to be effective practice is a considerable challenge.

- 6.3. Another focus of development in Europe has been on projects that have attempted to develop a more inquiry-based approach to the teaching of science. Notable amongst these are Pollen (www.pollen-europa.net) which is aimed at primary teachers in twelve European countries with an emphasis on teaching through inquiry; and Sinus and Sinus-Transfer which provide secondary school teachers in Germany with tools to change their pedagogical approach to science teaching in secondary school. The focus of these projects has been primarily on pedagogy and not on transforming the content itself. Such inquiry-based approaches are seen as providing children with: opportunities to use and develop a wider range of skills such as working in groups; more extended opportunities to explore their written and oral expression; and more open-ended, problem-solving experiences all in the belief that it will enhance student motivation and attainment. Some evidence does exist that these have been effective and it is these projects which are central to the recent report calling for a transformation in the pedagogy of science teaching in Europe^[4].
- 6.4. Another approach to the issue of engaging and motivating students has been to argue that the problem is that the more able students are insufficiently challenged by school science. Thus, in the Netherlands, a specialized science-enriched secondary school – Junior College Utrecht has been established^[44]. Entrance to this school is competitive and seen as high-status. Students are taught at an accelerated pace with students left to learn minor material independently. In addition, there is a greater research focus and a significantly enhanced curriculum in which university specialists teach specific modules. Students reported that they enjoyed the challenge, the enriched elements and working with their intellectual equals. Such a mechanism – essentially one of making the study of science a high status subject – is one means of attracting more able students.
- 6.5. The evidence of the effectiveness of these initiatives, however, is limited. In part as it is only when teachers have taught any course for a number of years, and adjusted their pedagogy appropriately, that it is possible to make a valid judgement on the outcomes. However, in all cases, research would suggest that students' understanding^[45] and attitudes are never worse, and often better. Clearly, when traditional approaches to teaching science are failing to interest and engage students with science, we would argue that sustaining such approaches is not an option.

Pedagogy

7. There is a limited range of pedagogical strategies used in the teaching of science.

- 7.1. The view emerging from the seminar discussions was that, in the past, too much emphasis has been placed on changes in curriculum. More fundamental is the need to transform the pedagogy of school science. Hence, it is essential that the EU and its member states continue to support innovative methods of teaching science and, critically, provide the continuous professional development necessary for teachers to adapt and transform their practice. No innovation will be sustained unless systematic and ongoing professional development is provided to support the changes required in the pedagogy of science teachers.
- 7.2. The traditional school science course serves as an introduction to a body of well-established knowledge that has the consensual agreement of the scientific community. Indeed, one of the distinguishing features of science is that its goal is to achieve closure. Once achieved, the community moves onto the next problem. The main challenge for the teacher, then, is to develop an understanding of this body of extant concepts, and ways of constructing meaning that rely on a specialist vocabulary of words, symbols, mathematics, diagrams and graphs – a meaning that is not open to multiple interpretations. To many a young person, the intellectual edifice seems profoundly authoritative and authoritarian – particularly when compared to other school subjects.
- 7.3. An accumulating body of research^[35, 36] shows that the pedagogy associated with this form of curriculum is one which is dominated by a conduit metaphor^[46] where knowledge is seen as a commodity to be transmitted. For instance, teachers will speak of trying to 'get across' ideas or that students 'didn't get it.' In this mode, little of the writing in school science transcends the copying of information from the board to the notebook. It is rare, for instance, to see any collaborative writing or work that involves the construction of an argument^[47]. Even experiments are written up formulaically. In addition, research^[48] shows that the nature of the discourse in this pedagogy is one which follows a pattern where the teacher will ask a question, the student responds with a short answer, and which is then followed by an evaluation of its correctness by the teacher. Little opportunity is provided for students to use the language of science even though there is good evidence that such opportunities lead to enhanced conceptual understanding^[49, 50]. This limited range of pedagogy is, it is believed, one reason why students disengage with science^[35].
- 7.4. The recent report produced by a team for the EU Directorate General on Research, Science, Economy and Society^[4] argued that a 'reversal of school

science-teaching pedagogy from mainly deductive to inquiry-based methods' was more likely to increase 'children's and students' interest and attainment levels while at the same time stimulating teacher motivation' – a view with which we concur. However, all the research on teacher professional development shows that changing teacher pedagogy cannot be done through short, one-off courses^[51, 52]. Rather it requires extended opportunities to engage in professional development, with good video-based illustrations of the kind of practice advocated and formative feedback.

Recommendation 5

Developing and extending the ways in which science is taught is essential for improving student engagement. Transforming teacher practice across the EU is a long-term project and will require significant and sustained investment in continuous professional development.

Assessment

8. Too little effort has been invested in developing more reliable, valid and engaging methods of assessment in school science.

- 8.1. Any teaching and learning experience is a synthesis of three components – a curriculum which defines both the goals and the experiences by which those goals will be achieved; a pedagogy which enacts the curriculum which is predominantly the responsibility of the teacher; and an assessment system. The last can usually either be formative – in that it seeks to ascertain student progress and adjust either the curriculum, the pedagogy or both to meet the learning needs of the students; or alternatively, summative where the function is to undertake a terminal evaluation of student attainment.
- 8.2. Commonly, research would argue that there are also three versions of any curriculum^[53]. The first is the intended curriculum – the one that is written or specified in syllabus documents, national curricula or schemes of work. The second is the enacted curriculum. All teachers have to translate the meaning and intent of any curriculum document into a set of learning experiences. Inevitably, there is a process of selection and emphasis which means that any one teacher's implementation of a curriculum is likely to vary significantly from another. Finally, there is the attained curriculum – essentially what level of knowledge and understanding the students have achieved.
- 8.3. Some would argue – as the American philosopher Dewey^[54] did – that when it comes to the implemented curriculum teachers should have as much professional autonomy as possible when it comes to educating students. The essence of their argument being that a teacher can only be seen as a professional if their life and actions are governed by their own judgement and not by external structures and agencies. However, in an era of political accountability, where performance is increasingly defined in terms of targets against which attainment is systematically measured, such freedom or trust is a diminishing feature of professional life. The consequence is that systems of assessment, be they local, national or international, have become increasingly important – not for measuring the attainment of the individual – but rather for measuring the *attainment of the system*. As their importance has grown as a measure of accountability, so have teachers increasingly looked not to the curriculum specifications to define what the intentions of the curriculum should be but to the assessment items.
- 8.4. The fact that such tests may have both questionable reliability and validity is forgotten. Rather, they have become a measure of the status and achievement of a country – an aspect, for instance, which was notable in the German and Spanish reaction to their performance on the TIMSS and PISA studies. The tests there were seen as valid and objective measures of performance that gave an accurate measure of student performance. This uncritical acceptance led to considerable questioning and examination of the weaknesses of their education systems that may have been unnecessary.
- 8.5. In such a context, the attainment of the system translates into a measure of the performance of states or regions within a country, then into an analysis of performance by schools and, ultimately, it is used for a comparison of the performance of individual teachers. Mistakenly, governments see these tests as a lever for improvement rather than investment in teachers, curricula or pedagogy. For the teachers, the attainment of their students on such tests becomes 'high-stakes' – a measure of their competence. To ensure that the performance of their students on such tests is the highest it can be, teachers, therefore, read the intentions of the curriculum not from the syllabi or textbooks but from the assessment items. A recent meta-analysis^[55] of the effects of such testing on school education has shown that it leads to the combination of contracting curricular content, fragmentation of knowledge into easily memorised chunks, and an increase in teacher-centred pedagogy – all aspects which the evidence discussed previously shows to be factors which alienate students from school science. Examinations, therefore, which only poorly reflect the intentions of the curriculum are likely to lead to an enacted curriculum that is a poor shadow of what was intended.

- 8.6. Traditionally, countries have invested little in developing the assessment systems and items that would accurately reflect the intentions of their curricula. Yet, as the previous argument has shown, it is the most crucial element. Indeed it would be more apposite to begin writing any new programme of study not by defining the curriculum experiences that might lead to any given set of desired outcomes but, rather, by reverse engineering the curriculum commencing by asking what kind of student performances would indicate that any given student had attained the intended curriculum goals? Only then would it be appropriate to ask what kinds of experiences might lead to such knowledge and understanding^[56]. To do this, however, much more investment is required in developing expertise in ways and means of assessing students in a reliable and valid manner by all countries.
- 8.7. What is needed are science courses that engage students in higher-order thinking which includes constructing arguments, asking questions, making comparisons, establishing causal relationships, identifying hidden assumptions, evaluating and interpreting data, formulating hypotheses and identifying and controlling variables. Assessment that is dominated by low-level cognitive demands risks too much emphasis being placed on the recall of factual information which often leads teachers into a pedagogy which emphasises rote learning. This approach undermines student interest in science. Improving the range and quality of assessment items used both to diagnose and assess student understanding of processes, practices and content of science should, therefore, be a priority for research and development.

Recommendation 6

EU governments should invest significantly in research and development work on assessment in science education. The aim should be to develop items and methods that assess the skills, knowledge and competencies expected of a scientifically literate citizen.

Teacher supply, professionalism and retention

9. There is large variation in Europe in teacher supply and teacher retention.

- 9.1. *Teacher supply:* There is substantial variation in the status and prestige of science teachers across Europe. After gender, research^[29] suggests that it is the quality of the teacher that is the major determinant

of student engagement with science. Recruiting and retaining the highest calibre teachers of science is, therefore, a critical factor in improving and sustaining the quality of school science education.

- 9.2. In countries such as Cyprus, Finland and Portugal, teachers still have high status and there is much competition to enter the teaching profession. The contrast is England, where there is a shortage of science and mathematics teachers despite considerable financial inducements and an extensive public recruitment campaign in the press and on TV. The group noted that there is little data available on teacher retention apart from in England. Here the data show that 50% of teachers of all subjects who begin training leave the profession within five years^[57]. The problem with teacher supply is also likely to be exacerbated in Northern Europe by the current age profile of many teachers of science. In Norway, for instance, half the teachers of physics are over 57. A similar but less severe situation exists in Denmark, England and the Netherlands.
- 9.3. In England, teachers commonly teach all three sciences at least to age 14. Likewise, in Norway, most teachers are required to teach two sciences. This is not so in countries such as Cyprus or Poland. The view of the group, though, was that the trend was towards teachers being required to teach more than one science – partly because of the increasing interdisciplinary nature of science-as-it-is-practised and partly because the old division of biology, chemistry and physics is difficult to defend when the astronomical, environmental and earth sciences can make legitimate claims for their importance. Nevertheless, because teachers' own education tends to be in one specific discipline, there is some resistance to this trend, as in France, where teachers generally do not wish to teach integrated science.
- 9.4. Where teachers of chemistry and physics are in short supply, teachers of science are often recruited from those with a background in the life sciences. When such teachers are required to teach chemistry and physics, at least in some countries such as the UK, the consequence of the lack of confidence in their own knowledge is that these subjects are not taught with the same expertise and enthusiasm to which European societies might aspire.
- 9.5. *Science teacher training:* All European countries require their teachers to have a relevant degree. In addition, some countries require the acquisition of a Masters degree whilst others require only an additional Postgraduate course. The move towards an emphasis on teaching for 'scientific literacy' and 'how science works'^[58] requires teachers to have a better understanding of the nature of their own discipline – something which undergraduate science education commonly fails to develop and an aspect which is exacerbated by the fact that few science teachers

have ever been practising scientists. This lack of understanding may make it difficult for teachers to meet the challenges of new syllabi such as Twenty First Century Science (UK) or the Dutch ANW course – both of which require a better understanding of the nature of the sciences^[43].

- 9.6. In countries such as Cyprus, there is a view that the training is too theoretically driven and not pragmatic enough, whilst in England the opposite is true. Theoretical knowledge is key to developing a professional language with which teachers can discuss and reflect critically on their practice with one another. For instance, some examples of educational knowledge that it might be reasonable to expect a science teacher to hold are some acquaintance with the ideas of Piaget about cognitive development; the ideas of Vygotsky on the significance of language to learning; and the extensive body of work that has been conducted on the common misconceptions that children develop about scientific ideas. Such knowledge is what demarcates the professional from the layperson. Science teachers need, therefore, both a knowledge of science and a knowledge of education. Another large body of teachers' knowledge is tacit – gathered through critical reflection and analysis of the plethora of events and interactions that occur in the classroom. Practice without theory is blind to the meaning of what happens whilst theory without practice lacks relevance. A balance of the two components is essential.
- 9.7. *Continuous Professional Development:* It was agreed that if teaching was to be seen as a profession there was a need for continuous professional development. This needs to be a normative expectation and not an optional extra. It is difficult to imagine anyone entering any other profession with an initial certification and not being required to participate in a systematic programme of ongoing education and training. The picture here was quite varied. England has recently established one national and eight regional science learning centres which offer professional development to science teachers. In addition, there are many other means of provision but there is no national system for its certification and recognition, unlike in Poland where there is such a system. Other countries rely on a mix of providers and let the market decide which of these are successful.
- 9.8. In Denmark, teachers who gain further qualifications are paid more. However, there is a risk that gaining such qualifications often leads to able and enthusiastic teachers being promoted to managerial positions where they are removed from the place where they are most needed – the classroom. Other professions – such as lawyers and doctors pay the top practitioners significant salaries and often less to their managers. Hence, teaching is at odds with law and medicine by rewarding effective and successful classroom practitioners by promoting individuals out

of the context in which they have demonstrated accomplishment. This is an issue that must be addressed if schools are to attract and retain individuals of high quality in the classroom.

- 9.9. The group were unanimous in their view that the most significant determinant of the quality of school science education was the quality of the teaching that students experienced^[29, 59] and, as a corollary, student interest in, and engagement with, science. Good science teachers are knowledgeable about science and its nature; have some understanding of basic educational ideas; use a range of teaching strategies; have excellent communication skills; and last, but not least, hold a passion for science.
- 9.10. Given that teachers of science are the most important resource for science education in Europe, it is essential that the recruitment of well-qualified and able teachers is a policy priority for all governments in Europe. Equally important is the issue of retention. Replacing any teacher incurs significant tangible costs in terms of recruitment and training a replacement. Less tangible, but as important, is the discontinuity in the school which requires students to develop a new relationship with yet another teacher and considerable effort to be expended by the established staff in inducting any new staff member.

Recommendation 7

Good quality teachers with up-to-date knowledge and skills are the foundation of any system of formal science education. Systems to ensure the recruitment, retention and continuous professional training of that such individuals must be a policy priority in Europe.

Conclusion

If there is one message that has emerged from our deliberations it is that the problems of the uptake of science by European youth are not amenable to simple, short-term solutions. More fundamentally we have argued that the primary goal of science education cannot be simply to produce the next generation of scientists. Rather, societies need to offer their young people an education in and about science – and that this needs to be an education that will develop an understanding of the major explanatory themes that science has to offer and contribute to their ability to engage critically with science in their future lives. In addition it should help develop some of the key competencies that the EU aspires to for its future citizens. Achieving this goal requires a long term investment in curricula that are engaging; in teachers of science by developing their skills, knowledge and pedagogy; and in assessment systems that adequately reflect the goals and outcomes we might aspire to for science education. The irony of the current situation is that somehow we have managed to transform a school subject which engages nearly all young people in primary schools, and which many would argue is the crowning intellectual achievement of European society, into one which the majority find alienating by the time they leave school. In such a context, to do nothing is not an option.

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