INCREASING HUMAN RESOURCES FOR SCIENCE AND TECHNOLOGY IN EUROPE

REPORT

to be presented at the

EC conference

EUROPE NEEDS MORE SCIENTISTS

Brussels, 2 April
2004

Members of the HLG
José Mariano Gago (Chairman)
John Ziman, Paul Caro, Costas Constantinou, Graham Davies, Ilka Parchmannn, Miia Rannikmäe, Svein Sjøberg

FOREWORD

On behalf of the High Level Group on Human Resources for Science and Technology appointed by the European Commission, I would be pleased to receive your comments to the attached report.

The High Level Group (HLG) is part of the Commission’s strategy to address the Lisbon EU Summit declaration of March 2000: that Europe should become the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion.
Since the Lisbon declaration, heads of state and government across Europe have continued to stress the need to boost substantially the number of people entering science and technology careers. Indeed, at the 2002 European Summit in Barcelona, heads of state called for an increase in the proportion of European GDP invested in research from 1.9% to 3%. In terms of human resources, it was estimated that an extra half a million researchers (or 1.2 million research-related personnel) would be needed to meet that goal.

A preliminary working document by the HLG was discussed at a restricted workshop held in Brussels on 1-2 December 2003. The objective of that workshop was to seek suggestions and comments from individual experts and relevant organisations.

Between August and November 2003, the HLG also received a large number of contributions in response to a wide consultation process it launched across Europe. Almost 200 national and European industrial organisations, universities and research laboratories, science and technology funding agencies and research councils, academies, scientific societies, science centres and science museums have devoted considerable efforts to providing the HLG with their views. Our final report will list all contributors.

In February 2004, the HLG held a meeting with national representatives appointed by their governments to interact directly with the Group. The purpose of that meeting was to clarify the strategies and objectives adopted by each European government, both at national and EU levels, in order to increase human resources for science and technology. This meeting was a follow-up to a special consultation process on this issue addressed to European governments. Written national contributions were received in February and March 2004, examining political objectives and programmes as well as detailed national statistics. All national contributions will be included as a special annex in the final report. However, as some national contributions have yet to be received, it is not possible to add this particular annex to the present report at this stage.

We are greatly indebted to the many individuals and organisations which have devoted considerable energy, competence and time to help us, and we would like to thank them all for their invaluable support.

We are also indebted to the EC services, notably DG Research (Directorate Science and Society and other Directorates) for their continuous support and information and for the proficient dialogue they have been able to establish with the HLG at all times.

We were fully aware that the mandate of the HLG could not be fulfilled without the involvement of the many stakeholders in science policy at national and European levels. Our goal was not only to analyse existing evidence and produce a report, but also, and primarily, to contribute to the strengthening of a constituency for scientific development in Europe. The involvement of the different social actors in science and technology policy was therefore essential for this purpose. Our experience has shown that the issue of human resources for science and technology is probably one of the best at present, both as a unifying objective and as a strategy to be shared and supported by society at large.

However, we should point out that our efforts must be seen as a preliminary phase of the work that should be accomplished in the near future. In our view, considerable time should be devoted to setting up a dialogue in each Member State on the issue of human resources for SET in order to contribute to the understanding needed by policy-makers and the catalyst required to provide the convergence of different players at national and European levels. The dialogue that has been initiated with industrial and academic organisations in Europe should be pursued. There is a need to convey to both national and European statistical bodies and to the OECD the expertise acquired in trying to understand conflicting and flawed statistical evidence. Finally, there is a need to liaise with the various groups and the EC services that are effectively contributing to our understanding of the multiple factors contributing to the SET human resources issue in Europe. The integration of knowledge that is increasingly needed to assist policy-making in Europe requires this type of effort.

The present text is the HLG’s preliminary report. Our final report will include the aforementioned annexes and a revised and extended version of our conclusions and recommendations. It will also integrate the results of the professional editing of the whole document, including the checking of the many references and statistics quoted.

March 2004
José Mariano Gago
Chairman of the High Level Group

EXECUTIVE SUMMARY

1. What is at issue?

Through a succession of European summits from Lisbon in March 2000 to Barcelona in March 2002, the strategic European goal was set: an increase in the average European GDP dedicated to research to 3% by 2010. Human resources growth associated with this target is of the order of 1.2 million additional research personnel (or about half a million extra researchers).

The High Level Group (HLG) at the origin of the present report was set up to identify specific actions or policy measures which, within the context of the European Research Area, could help towards this goal. We conducted a review of the main actors able to contribute in one way or another to human resources, from the research institutions and industries employing R&D personnel, to the educational process from secondary schools to universities, and to public opinion. ‘Research’ has been understood in a very broad sense. The workforce involved has been defined as people entering into the different statistical sources as ‘Science, Engineering and Technology’ (SET). SET careers depend on a wide range of diplomas, or other types of qualifications, associated with different forms of training, a varying number of years of study, and also on skills.

2. The crisis in the production of human resources for S&T

In 2001, the number of researchers per 1 000 of the workforce (in full-time equivalent, FTE) was 5.7 for the EU-15 (3.5 for acceding countries). Finland tops the list with 13.77. Between 1996 and 2001, the average annual growth rate was 2.6% for the EU-15 and 2.1% for acceding countries. For a majority of countries, employment in R&D has grown at a faster rate than total employment in the period 1995-2002, but there are large individual differences between the European countries. In the 1990s, the number of researchers per 1 000 labour force increased more than 100% in Greece and Portugal and over 50% in Austria, Finland, Denmark, Sweden and Belgium.

However, those figures should be compared to a value of 9.14 researchers per 1 000 of the workforce (FTE) for Japan and 8.08 for the USA. Only some countries in Europe (Finland, Sweden, Norway) reach that standard and the most populated ones show much lower figures (Germany 6.55, UK 5.49, France 6.55). There is an important margin of progress possible in Europe to increase human resources in R&D.

The Lisbon and Barcelona EU objectives of attaining 3% of GDP for R&D (from the present level of around 2%) will roughly require a minimal level of eight researchers per thousand in the workforce. However, this objective will not be reached within a reasonable time (and certainly not in 2010, as targeted by the EU summits) should the present trends continue unchanged. On the other hand, a clear departure from stagnation or reduced growth rates in R&D employment in Europe will require important changes in the most relevant factors affecting this outcome. Our major concern is to understand how national and European policies may effectively contribute to that ambitious objective.

We have studied data describing, country by country and by disciplinary groups, the different classes of graduates in S&T in engineering and science. Comparisons between some of the most populated countries – Germany, France, UK, Spain, Italy, Poland and Netherlands –

allowed us to visualise the different trends. The decrease in science and engineering graduates (all tertiary levels) over the period 1998-2001 is clear for Germany and the Netherlands and, in Italy, for science graduates alone. The other countries show increased numbers of graduates, some with sharp rises (Poland). The breakdown by disciplinary areas shows that the physical sciences and mathematics are the most affected, other fields (life sciences and computer sciences) either remaining stable or increasing. At PhD level (examined for Germany, France and the UK) the trend is the same with decreasing numbers observed in Germany, which are confirmed by a graph showing the evolution of the number of all S&T graduates in this country between 1993 and 1996 that exhibits either a decrease (engineering) or flat curves. Nevertheless, there are signs of a recent recovery in the number of students entering university in SET courses in Germany.

Comparisons are offered with science and engineering graduates in six other medium-sized countries: Austria, Finland, Hungary, Ireland, Norway and Sweden. The results are very different with some important decreases (Hungary) and sharp rises (Ireland, Sweden) illustrating the contrasting situations in Europe due to different dynamics in the national economies. Two final diagrams show the total number of graduates (all disciplinary fields including humanities). There has been an increase in Europe with the important exceptions of Germany and Netherlands. The curves for PhDs are slowly rising, showing no drastic change in the rate of ‘production’ over the years covered (1998-2001). Germany has the lead with two and a half times more ‘Doctors’ than France and the UK. There is a paradox in the German data: two times less university graduates than in France and the UK but a ratio of researchers to 1 000 workforce equivalent to one in France and slightly above one in the UK. Moreover, Germany has a share of population (aged 25-59) with upper secondary education of more than 80% (as in the UK, to be contrasted with only 64% for France and much less for the other southern Europe countries).

As this report was being completed, results were made available of an important study (MAPS – ‘Mapping Physics Students in Europe’) conducted by the European Physical Society as a contribution to the HLG. Although they cannot be included in this version of our report, they will be presented at the conference and incorporated in the final HLG report. This study shows namely that the number of graduates in physics dropped by 17% in Europe between 1997/8 and 2001/2. A possible sign of a recovery is that a reduction in the number of students entering physics studies was only 2.7% in the same period.

We have also studied national statistics on higher education for three countries: France, Germany and the UK. Those statistics provide the number of students entering an academic field at their entrance into the university system and on the resulting diploma obtained by those who stayed in the system. Evidence of disinterest in all three countries as regards ‘classical’ fields, such as mathematics and physical sciences (which includes physics and chemistry, among others), is very clear. Students’ interest has shifted to life sciences and computer sciences whereas engineering fluctuates (1998-2001). But the paradox is that the numbers of higher tertiary graduates are increasing at times when the numbers of lower graduates are diminishing. Consequently, there is a clear risk of numbers of highly qualified tertiary graduates (PhDs) diminishing in the near future. Students entering universities can react quickly to changes in the work market by shifting to another more promising sector, but this is not the case for advanced graduates who are stuck in their speciality after several years of study and may fall victim to an unfavourable economical cycle situation. This shows how important it is to provide counter cycle measures to prevent the wasting of human capital in such situations.

The number of S&E graduates in Europe is higher than in the US and Japan, but the proportion of people aged 25-64 with a university degree is much lower in Europe than in Japan and the US. Europe's strength is in its younger fraction of the population trained in S&T. Europe would be catching up with the US and Japan in terms of researchers by 1 000 workers if employment in R&D were available for young people, if the numbers of those who choose to study S&T were not allowed to diminish, if more women were involved in R&D, and if the southern countries accelerated their S&T development. In particular, educational achievement and the rapid reduction of unacceptable, early drop-out rates in many European countries will be key policy objectives to broaden the qualification pool for S&T professions.

As most of the employment for researchers is created by industry, better conditions for the development of research by the private sector have to be reinforced in Europe, if the Lisbon and Barcelona goals are to be met. On the other hand, the level of public funding per researcher in Europe is clearly well below that in the US. It is not surprising, therefore, that the number of European researchers, namely in the public sector, does not translate into the same level of working conditions and, consequently, of results. The conditions and prospects for employment by the public sector (by universities, public research centres or other publicly funded research institutions) should be recognised as critical for the EU strategy. New human resources for S&T will not be attracted at the required level unless governments translate their own political goals urgently into new research jobs and better career perspectives. In periods of economic slow-down, this conclusion is even stronger.

3. Demand and supply in the SET labour market

This chapter explores where this demand is likely to arise and the concomitant implications for the supply side. It has been shown that the largest increases in R&D spending will have to be met by industry. EU industry spending on R&D lags well behind that of its competitors in the USA and Japan. It has proved to be a recondite task to estimate exactly where and in which sectors of the economy the demand will be most keenly felt. In any knowledge-based economy it is prudent to expect the demand to be across all industrial sectors. This does not ignore the fact that well-established industries will be drawing heavily on new technologies to make their business more competitive in the global market place. In addition, technology and the acquisition of technology has become global over the past few years, and this has given rise to a new paradigm in R&D. Businesses can no longer go it alone – they have to rely on new players in the technology stakes, whether or not this means exploiting their supply chain, venture funds, academia or inorganic acquisition via start-up companies. This has lead to the death of the concept of the corporate laboratories and corporately funded R&D. In general, they have now become the integrators of technology, not the primary movers in its discovery. This in itself has led to a new role for universities where, in partnership with industry, they will become the outer 'radar' for businesses on new technology.

From a supply perspective, it can been argued that on the present trajectory of increasing the numbers entering SET careers, EU ambitions will not be met. There is a need for a step-change in recruitment into SET at all levels. Dramatically increasing the number of women entering SET careers would go a long way towards helping to solve the problem, whereas reliance on importing suitably qualified workers from outside the EU is not sustainable in the long term, given the global nature of the market and the dynamics at play. It should not be forgotten that the EU itself is a source of such workers for other knowledge-based countries.

When this is put alongside the ageing SET population, the growing shortage of teachers, and the greying of academic staff, then the situation becomes serious. Only radical solutions are appropriate and must include the commitment to inject large portions of both national and Commission budgets into solving the problem. It is also apparent that this shortage is not felt across the whole of Europe, although it is argued that this in itself is not a steady state and that migration to satisfy demand will surely occur. The need for standards in education and qualifications will be necessary if the ERA is to succeed. The Bologna Accord is a start in this process but it will only be successful if it embraces credit transfers and not time served on academic courses.

4. Career perspectives

There is a widely held perception that careers in science, engineering and technology are very unattractive and hold little appeal to young people. This perception covers remuneration, career structure, work environment, status and marketing. This chapter examines these perceptions as they might apply to industry, academia and government. From an industrial perspective, these perceptions are not found to be true (although more evidence across all European countries is probably needed). Remuneration of SET workers is in the upper quartile of professions and the sustainability of remuneration is shown to hold for at least 11 years into their careers. It is also true that unemployment amongst holders of SET tertiary education qualifications is lower than that of the population at large. The diversity of careers for people with an SET background is shown to be great and probably far more varied than any other sector. Taking all these aspects into account, it is difficult to understand why there are such difficulties in recruitment. The conclusion has to be that industry and the profession are not selling careers in SET in the most attractive fashion, which is certainly an area for future attention.

Despite the risk from employment uncertainties – an aspect that must be true for every sector of the economy these days – industrial careers are shown to contrast with careers in academia and the public sector. Remuneration in the public sector is poor and career structures are not conducive to attracting both the quality and quantity of qualified people that are required. Although there are other aspects of employment that do attract people to this section, these are not enough to tip the scales in favour of large numbers of people wanting to enter these professions. This is certainly an area that needs the full spotlight of national and European policy to be directed towards it as there are serious deficiencies now that need to be remedied. This chapter discusses these in full.

There is a general conclusion that the main emphasis on closing the 3% gap lies mainly with industry, so industry needs to promote careers in a more attractive way to prospective SET employees. However, it is not a job for industry alone. National governments, as well as the Commission, have a significant role to play and it is only through a coordinated approach that the problem can be solved. Good, well-remunerated, attractive careers in the public sector and academia need to be in place and marketed as such to future generations if the entire ERA and knowledge-based economy are to be fully realised. This is absolutely key to the future prosperity and competitiveness of the European zone.

5. Higher education and research training

There is a need for higher education institutions to shift their scope and mode of operation from preparing experts for an industrial society to educating reflective personnel capable of contributing towards meeting the needs of a knowledge society. Instead of presuming that all their SET students are headed for academic careers, universities should cater for and celebrate the whole range of research employment, including the relatively less-prestigious jobs that many of their graduates will actually be taking. Curricula should be less 'theoretical' and should reflect more directly current societal SET needs. Important job skills for all employment sectors include writing, oral presentation, management, data analysis, project design, critical thinking and collaborative work, and the ability to handle uncertainty in an interdisciplinary context. Research training in association with and opening into industrial R&D might also take the place of doctoral and postdoctoral programmes for many graduates. Full access for women and ethnic minority groups to courses leading to research careers should be further emphasised. The involvement of undergraduate students in research activities as a normal part of their curriculum is still very exceptional. Opening research laboratories and industries to undergraduates in SET would promote a more realistic perception of research by students and could effectively contribute to increasing rapidly human resources for SET in Europe.

6. Schooling for science, engineering and technology

Post-secondary schooling, especially at PhD level and beyond, plus training within science, engineering and technology establishments is specialised and caters for Europe's needs for a high-level workforce. The education provided is for mature students or adults and is able to build on their strong self-interest and motivation to raise their levels of expertise.

This contrasts greatly with education at the primary and secondary levels, most of which is compulsory across Europe. Here the education is given to develop the student, both individually and socially, to gain knowledge, skills and attitudes that relate to the cultural societies in which the students find themselves. The students are far from being adults and schools have a responsibility to develop their mental, physical and emotional capabilities. In most schools this happens by dividing the school curriculum into subject areas so that the educational developments, which are expected to meet society's needs, are approached through the context of different subject areas.

Engineering is very rarely taught as a school subject. It is regarded as an aspect of technology, as are fields such as medicine and computer science (not computer education – this is promoting education through a context of a communication ability). Technology itself has a mixed development, sometimes mistaken for the promotion of computer skills – a communication skill and all too often mistaken for technical training, promoting psychomotor skills without the technological, theoretical underpinning. But science education (the teaching of science in schools) is universal and is often an umbrella for the teaching of science and technology, and is frequently subdivided into sub-branches such as biology, chemistry and physics, especially after the ages of 12-14.

All school education is driven by the aims put forward by society in the different countries and enacted by Ministries of Education. These aims are remarkably similar in wanting to promote intellectual, communicative, personal and physical, co-operative, social/moral skills and values. The students are being prepared as responsible citizens able to play a role within society, either through their individual prowess, or collectively in the decisions to be made, especially in an advancing scientific and technological world, or in a knowledge-based society. All subjects thus relate to these aims. They strive to develop the students not only in their intellectual capacity, but also to cater for their interests and talents and by developing lifelong learning skills such as ‘learning to learn’, and social values such as ‘respect for human rights’, ‘the need for sustainable development’, and ‘the promotion of tolerance and peace in the face of conflict’.

Unfortunately, science education has been inclined to isolate itself from the rest of education and has tended to be separated by society into its own subculture. There is a strong tendency to regard the teaching of science not as an area of educational development of the student, but solely for the pursuit of the subject matter. Science education is viewed as the learning of ‘science knowledge’, rather than ‘education through a context of science’. There is thus pronounced confusion between science on the one hand and science education (that which is promoted in schools) on the other. This is propagated by teachers and others and translated into teaching students to become ‘little scientists’. The teachers thus stress the move away from the stated aims of education linked to the development of the student to become a responsible member of society, of which developing his or her intellectual prowess is but one component.

Therefore, there is both an image and direction problem within primary and secondary education that needs to be addressed. While education has to make students aware of career opportunities and develop their interests and skills to match their aspirations, this must be the province of education as a whole, not simply science education. And, of course, science education must guide students to develop the skills, interests and attributes to provide the support for those students wishing to follow highly skilled technological or scientific careers. But this must be a component of education through science, not a separate, highly academic provision.

There is little doubt that, in developing students’ interests and motivations towards science and technology and allowing them to become familiar with the fast-advancing developments in this area, it is essential that science education is on the curriculum from an early age. Science education should form a key part of the primary curriculum. But in recognising that students at this age are unable to cope with abstract ideas and tend to gain much from personal involvement activities, the ‘hands-on’ science education provided is readily accepted by students. Through this approach, it is easy to motivate and interest both boys and girls. This has been shown extensively across Europe by science centres, where the majority of visitors tend to be young children either attending in school groups or accompanied by their parents.

However, primary science, although very valuable and important, does not directly relate to careers. And the interests and motivation cultivated are not so easily sustained at the secondary-school level or, to recognise the hurdle more explicitly, beyond the onset of adolescence. It is the secondary school that is faced with the need to develop the intellectual capacity, to move to more abstract forms of thinking while coping with the students’ own adolescent development and the change of interests that brings. For example, there is often a strong development of interests outside the school which compete with the need for intellectual work inside the school. This is amplified by the difficulty in allowing education to keep pace with developments, both in terms of the society’s changing needs and the attractiveness by which student distractions, or entertainment, are presented.

Science education suffers badly in this respect – not only is it trying to cope with this image of 'becoming a scientist', but it is also fighting to relate to society. And yet it is being bound by an old-fashioned view that it must develop the 'fundamentals' which, all too often, are abstract, even microscopic, and far from the science ideas underpinning the technological advances within society which form the focus of debate and divide public opinion. It can be argued that science education in schools lives in a world of its own. It is unsophisticated because it is unable to compete with advances within the scientific fields. It is perceived as too abstract because it is trying to put forward fundamental ideas without sufficient experimental, observational and interpretational background, without showing sufficient understanding of their implications, and without giving students the opportunity for a cumulative development of understanding and interest. It is heavily in danger of being excessively factual because of the explosion in scientific knowledge and the 'adding-on' of topics to an already excessive content base. And, to add to all this, the measures of assessment of student achievement has been largely confined to the regurgitation of information.

And finally, the poor image and perceived relevance of science education impacts on the career aspirations of students. While students see and may even interact with medical practitioners within society, and are familiar with the technology products that have been developed within society, there is little opportunity for students to experience careers in industry, in establishments not open to the public, or in areas where the career is pursued away from the public gaze. This problem is not easy to address. Making students aware of famous scientists, aware of the ways in which industry operates and how they strive for public support so that they can operate and enable society to prosper, are important. But they are no substitute for the 'real thing'. Countries have developed programmes of work experience to try to bridge this gap, but there is still no concluding evidence that this encourages students towards careers in these directions. It seems the best we can do is to modernise the educational approach to science and technology education, make the school 'education through the context of science' more acceptable to society, and enhance student and guardian awareness of career opportunities that relate to the fields of science, engineering and technology. Unfortunately, we are unlikely to do that through the pursuit of international competitions.

7. The cultural context of recruitment for research careers

Strategies for science popularisation have been in use since the 17th century, and remain very active today. They are usually supported by governments, public institutions, research organisations, scientists, museums, and science centres using a variety of forms. They can be divided into two approaches: classical public understanding of science trying to bring more information and knowledge of science matters to a general public and to young people; and a networking approach based on the idea that extended dialogue and direct contact between citizens and scientists is necessary in order to promote scientific culture in society and to help citizens to acquire a better understanding of controversial issues related to science and technology.

It has been pointed out that the rational basis of the science invented in Europe and its goal to "tame" Nature met strong resistance in European history. This feature of European culture deserves special attention today as the very image of science and technology in society and students' attitudes to science seem to reflect this fundamental duality.

Media are a very important intermediate between science and people – 60% say that they get their scientific information from television. However, the media (TV, radio, movies, newspapers, magazines, novels, comics, etc.) have their own rules and use science and technology mainly as a source for narratives that attract people through conventional storytelling and spectacular images or situations. Nevertheless, they make science familiar and this is a main point of entry for the introduction of science into society. In this respect, some EU data from recent public opinion surveys about science and technology and knowledge issues have also been summarised.

Certain economists doubt that actions to improve science popularisation and even science teaching at primary and secondary levels are really helpful in increasing recruitment into science careers. They believe that the most important point, on which efforts should be concentrated in Europe, is at university level. We do not agree with these views which, in our opinion, disregard the social and cultural context of scientific development in democratic societies and the need to reinforce and widen the social constituency able to support scientific and technological development, namely the very wish to study science and to pursue science and technology careers.

8. Women in science – filling the gender gaps in science and research

The number of women in education and in employment across Europe has increased in the last 20 years, as indeed has the number of women entering science. However, women remain severely under-represented in many areas of scientific research and in many countries, and are still not reaching the upper echelons of the research hierarchies.

Much has been achieved in promoting women's participation in scientific research. since 1999, when the European Commission launched its action plan on women and science, in co-operation with Member States and other key actors. As a result, there are a number of reports and statistical documents devoted to this subject. For this reason, this section seeks only to provide an overview of the situation.

Women remain the most obvious source for increasing human resources for science and technology in Europe. However, drastic changes in the present unsatisfactory situation can only come from joint consistent efforts by both science policy and social and economic policies.

Table of Contents

1 What is at issue?

Summary

This chapter presents the policy background against which the current work was undertaken. It starts with the creation in January 2000 of the European Research Area to coordinate the development of research capacity in Europe; through a succession of European summits from Lisbon in March 2000 to Barcelona in March 2002, a strategic European goal was set: increase the average European GDP dedicated to research to 3% by 2010. Human resources growth associated with this target is of the order of 1.2 million additional research personnel.

The High Level Group (HLG) whose findings are represented in this report was set up to identify specific actions or policy measures which, within the context of the European Research Area, could help towards this goal. We conducted a review of the main actors able to contribute in one way or another to human resources, from the research institutions and industries employing R&D personnel, to the educational process from secondary schools to universities, and to public opinion. 'Research' has been understood in a very broad sense. The human resources that are at the centre of attention here are those involved in 'Science, Engineering and Technology' (SET). SET careers span a wide range of diplomas, or other types of qualifications, associated with different forms of training, a varying number of years of study, and also skills. This complexity makes the field difficult to comprehend.

1.1 The policy setting[1]

In January 2000[2], the European Commission published a new policy to support research in Europe. This policy called for the creation of a European Research Area to bring within one co-ordinated approach all the elements that contribute towards the development of research capacity in Europe, as well as to integrate the aspirations and needs of society into the development of science.

At the March 2000 European Summit in Lisbon, heads of state and government committed themselves to turning Europe into the most competitive and dynamic knowledge-based region of the world by 2010, capable of sustainable economic growth with more and better jobs and greater social cohesion. The development and use of scientific knowledge was established as a key strategic element.

In March 2001, the European Summit in Stockholm called, *inter alia*, for the establishment of a work programme on a follow-up of the objectives as regards education and training systems. Subsequently, the European Summit in Barcelona in March 2002 adopted a work programme, and working groups were set up to address the specific objectives identified. One such working group is dealing specifically with the issue of *increasing recruitment to maths, science and technology studies*.

---

[1] HLG Terms of Reference (TOR), April 2003

[2] COM(2002) 6 18.01.2000

The Barcelona Summit also quantified the Lisbon objective in terms of increasing the percentage of average European GDP dedicated to research from the current level of 1.9% to 3% by 2010. In September 2002[3], the Commission published a Communication on '*More Research for Europe: Towards 3% GDP*', and in April 2003[4], in a further Communication on '*Investing in Research*' set specific targets in terms of the human resources necessary:

"*Increased investment in research will (must) raise the demand for researchers: about 1.2 million additional research personnel, including 700 000 additional researchers are deemed necessary to attain the objective – on top of the expected replacement of the ageing workforce in research.*"

Meanwhile, a Report entitled 'Researchers in the European Research Area, one profession, multiple careers' was published in July 2003 [5] (**ERA**).

1.2 Objectives of the present report

For a number of reasons that will be set out in detail later, it soon became apparent that this target would not be attainable without deliberate and sustained positive action. The current facilities for producing trained researchers are geared to a much slower rate of growth than is now envisaged. Clearly, these resources could not meet this demand unless substantially augmented and/or reformed. It seems unlikely, moreover, that the problem could be solved simply by "throwing a lot more money at it". Major structural changes will be required, at all levels, in the various national procedures by which researchers are educated, trained and recruited.

Therefore, a High Level Group was commissioned to identify specific actions or policy measures that could be initiated in the course of 2004, and subsequently, that would make a substantive contribution towards increasing the number of research personnel (in particular) and science professionals (in general) in Europe. This working document is the fruit of our deliberations.

Our recommendations are designed to be applicable at the political and policy level within the context of the European Research Area. They cover actions that can be directly implemented through the mechanisms of the Sixth Framework Programme, notably within the context of the 2004 work programme of the Science and Society action line of the specific programme on Structuring the European Research Area. They will also address actions to be pursued at national or international levels by other mechanisms.

As requested, we have endeavoured to identify the agents for action, the means by which action can be supported, and the criteria against which impact can be clearly appraised and evaluated. It soon became obvious, however, that the issues at stake are of a kind that can only be resolved by co-operation between all the actors in the system – policy-makers in government and industry, teachers and educationalists, scientific notables, media communicators and, last but not least, researchers themselves. This requires them all to become aware of the general nature of the problem so they can each work out how to coordinate their own particular efforts with those of others.

This report, therefore, also seeks to analyse the situation in these broader terms. In developing this analysis, however, we became conscious of the extreme diversity of the elements, national and

---

[3] COM(2002) 499 11.09.2002
[4] COM(2003) 226 30.04.2003
[5] COM(2003) 436 final 18.07.2003

international, public and private, that combine to make up the European Research Area. We have therefore indicated some of the topics that would surely repay further systematic investigation, discussion and decision, and suggested constituencies and fora where these studies might be undertaken.

1.3 The scope of the inquiry

The objective of 'increasing the number of research personnel and science professionals in Europe' seems admirably clear. But how widely should these terms be taken to apply? In its Terms of Reference, (TOR), the HLG was requested to define **research** very broadly so as to cover all forms of *creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications*[6]. We do not therefore use the compound term 'R&D', but include in 'research' the activities designated as '**experimental development**' in the sense of the Frascati Manual definitions.

On occasion, we find it convenient to differentiate between various modes of research, such as **pure research**, **basic research** and **applied research**, or to refer to mixtures of these such as **strategic research**. This allows for the optional further breakdown of basic research into **pure-basic** and **orientated-basic** and for the long-standing UK practice of subdividing applied research into **strategic-applied** and **specific-applied**. But the distinctions between these categories are ill-defined, both in principle and in practice, and turn out not to be relevant to our report, so we use them loosely, as customarily understood.

On the other hand, the overall policy goal is to enhance the economic competitiveness of the Community through technological innovation. Although R&D is often the most important part of this process, the success of new products and processes depends heavily on a wide range of other non-scientific factors. Our brief therefore covers the **transfer** of knowledge out of the realm of 'research', whether or not this knowledge was discovered or acquired in the pursuit of a particular application. In other words, it includes a variety of activities associated with **technology transfer,** the general **dissemination** and **application** of scientific and technical knowledge, and scientific and technical **education**. For practical reasons, however, it excludes all those other scientific, technical, commercial and financial steps that are often necessary for the successful development and marketing of new or improved products, processes or services.

1.4 Organisational settings

Another way of defining the scope of our enquiry is to confine it to the organisational settings where 'researchers' (and other R&D personnel) are normally employed. These are very diverse and heterogeneous, since they typically include the following:

- **Universities**, which not only play a vital role in knowledge transfer through science education and researcher training but are also heavily engaged in long-term basic and strategic research projects that are essential to the knowledge-based economy.

- Public or private 'not for profit' **research organisations**, such as research councils, academies of science, and charitable foundations. These differ from country to country and

---

[6] Proposed Practice for Surveys on Research and Experimental Development, Frascati Manual, OECD, 2002

from one type of research activity to another, with varying combinations of strategic and applied (market-oriented) research.

- **Governmental bodies** providing research-based knowledge for application in such public services as environmental protection, public health, national security, etc.

- **Industrial corporations**, ranging from large private companies and public-sector utilities mainly engaged in specific-applied research (but often with active interests in strategic research), to technologically based SMEs[7] principally engaged in market oriented research and technology transfer.

This list, however, is far from exhaustive. Much research and knowledge transfer takes place; for example, in **hospitals**, as an essential adjunct to their prime social functions. Not all medical practitioners or other health service professionals should be counted as 'researchers', but many people are employed by these institutions to perform both roles. Again, as we shall see, we include the science teachers in **secondary schools**, not only because they are usually scientifically qualified to first degree level but also because of the very important part they play in the recruitment of young people to research careers.

It is clear, therefore, that it is not satisfactory to define 'researchers' in terms of their place of employment. These locations are not only very heterogeneous. In many organisations, also, professional research scientists only form a small proportion of their employees, and may not be sharply differentiated from the rest.

1.5 Defining the SET Workforce

Official statistics often apply the label **'Science, Engineering** and **Technology'** to this category of employment. Again, the precise definition of these terms varies from country to country. In this Report we shall use the acronym **'SET'** quite generally to comprise:

- **Science –** the systematic study of the nature and behaviour of the material and physical universe, together with mathematics, the social and economic sciences and some branches of the humanities;

- **Engineering –** the practical application of this knowledge in industry, defence, commerce and other civil activities; and

- **Technology –** the socio-economic use of the tangible products of science and engineering.

We agree, however, with Roberts[8] that this definition of SET should not be considered exclusive, and that it is essential to recognise "*the powerful influence of multidisciplinary and interdisciplinary activities in innovation, where related subjects (for example, medicine and information studies) are increasingly important, and that consumer-led demand is a powerful motivator in the production and development of novel products and services*".

---

[7] SME: Small and Medium-sized Enterprises

[8] The report of Sir Gareth Roberts' Review: "SET for success": The supply of people with science, technology, engineering and mathematics skills, April 2002

1.6 The linked hierarchies of SET qualifications and jobs

Considered as a human resource, however, the members of the **SET workforce** are distinguished less by the actual jobs that they do than by their **skills.** Although these are the diverse outcomes of individual experience in education and employment, they are publicly attested by various formal **qualifications**. These are easily defined and enumerated statistically, but vary bewilderingly between national education systems and even between SET disciplines in each country.

Nevertheless, for our present purposes, **SET qualifications** can be roughly graded into a three-level hierarchy. Each of these grades qualifies for entry at the corresponding level in the hierarchy of **jobs** in SET-based organisations. In general terms, these are as follows:

Baccalaureate. We use the French name for the qualification typically acquired by successful completion of **secondary education**. Throughout the EU, this level of academic competence is a prerequisite for entry into **higher education**. This qualification – or one of its more vocational equivalents – is also the minimum requirement for a '**technical**' job in a research organisation.

Bachelor's degree. We use the English-language term for the qualification acquired on **graduation** from a 'first cycle' of several years of higher education. It is the minimum qualification for **professional** SET employment, whether as an apprentice researcher or as a **technical practitioner**, teacher, educator, or communicator.

Doctorate. The PhD degree (or its equivalent) certifies the successful outcome of several **postgraduate** years of **research training**, typically including the presentation of an original **dissertation** showing mastery of a specialised SET field. It is a prerequisite for further progression within academia and is also the normal qualification for a responsible post as a fully-fledged **professional researcher** in a research organisation or industrial corporation.

In most SET careers there are also intermediate qualifications, such as postgraduate **Master's degrees**, and indeterminate levels of employment, such as **postdoctoral fellowships**. In practice, SET workers can often rise to higher levels of employment on the basis of proven experience, without gaining the corresponding certificate, diploma or degree. Nevertheless, this linkage between formal qualifications and job responsibilities is one of the defining features of the SET workforce throughout the Community, and has to be clearly understood as a major factor in its putative expansion.

We must emphasise, however, that this linkage should be considered as purely functional. Particular SET jobs are usually so highly specialised that they cannot be undertaken at all without the appropriate minimum of specialised skill. But the possession of a particularly rare skill should not be taken as a sign of élite status. To quote from **ERA (**ref. 4, page 7):

"It is observed that the status of researchers is appreciated differently by the scientific community depending on the sector, the research setting or the type of research undertaken. Given, however, that all contributions are essential to the development of the knowledge society, it is necessary to consider any activity directly or indirectly related to R&D, including the management of knowledge and intellectual property rights, the exploitation of research results or scientific journalism as an integral part of a career in R&D."

At a later stage we will see the importance, in the context of our own report, of their further comment (ref. 4, page 7):

"The policy lesson is that any of those careers will have to be treated and valued on equal footing without maintaining the preponderance of an academic research career as the only benchmark for attracting young people into such a career track. In addition, lifelong professional development opportunities in different research settings should be made more relevant for a wider variety of careers than in the past.

In this connection, we fully concur with the following remarks in a **US Report**[9]:

"There are a number of definitions for the science and engineering workforce. The most common is to count those in occupations classified as science and engineering positions. However, this approach fails to identify those with skills in science and engineering used in non-S&E occupations – for example, in technical management. The task force has focused on the availability of skills, in view of the fluid nature of the science and engineering workforce – with members capable of employment in a number of kinds of occupations over the course of their careers. In this definition, a pre-college teacher with a baccalaureate or the equivalent in a field of science, mathematics or engineering is a member of the science and engineering workforce. Also included are practitioners with two-year degrees and certificates in science, engineering and technology fields.

"This approach appears to be more in keeping with how degree holders view themselves. For those with science and engineering baccalaureates or higher-level degrees in the [US] workforce in 1999, 67 percent in occupations not formally classified as S&E jobs stated that their jobs were at least somewhat related to their highest S&E degree field. In 1999 there were 10.5 million S&E degree holders at the baccalaureate level or above in the workforce. For the purposes of this study, this group along with those with associate degrees in science and engineering are considered the qualified pool of scientists and engineers."

---

[9] Draft Report, National Science Board, Committee on Education and Human Resources, "Task Force on National Workforce Policies for Science and Engineering", 22 May 2003, p.14

2 The crisis in the production of human resources for Science and Technology

Summary

In 2001, the number of *researchers* per 1 000 of the workforce (in full-time equivalent, FTE) was 5.7 for the EU-15 (3.5 for acceding countries). Finland tops the list with 13.77. Between 1995 and 2001, the annual growth rate was 2.6% on average for the EU-15 and 2.1% for acceding countries. For a majority of countries, employment in R&D has grown at a faster rate than total employment in the period 1995-2002, but there are large individual differences between the European countries[10]. In the 1990s, the number of researchers per 1 000 workforce increased by more than 100% in Greece and Portugal and over 50% in Austria, Finland, Denmark, Sweden and Belgium.

Those figures should be compared to a value of 9.14 researchers per 1 000 of the workforce (FTE) for Japan and 8.08 for the USA. Only some countries in Europe (Finland, Sweden, Norway) reach that standard and the most populated ones show much lower figures (Germany 6.55, UK 5.49, France 6.55). There is consequently an important margin of progress possible in Europe to increase human resources in R&D, namely in the central and southern European countries.

The Lisbon and Barcelona EU objectives of attaining 3% of GDP for R&D (from the present level of around 2%) will roughly require a minimal level of eight researchers per thousand in the workforce. However, this objective will not be reached within a reasonable time (and certainly not in 2010, as targeted by the EU summits) should the present trends continue unchanged. On the other hand, a clear departure from stagnation or reduced growth rates in R&D employment in Europe will require important changes in the most relevant factors affecting this outcome. Our major concern is to understand how national and European policies may effectively contribute to that ambitious objective.

We have studied OECD data describing, country by country and by disciplinary groups, the different classes of graduates in S&T in engineering and science. Comparisons between some of the most populated countries, Germany, France, UK, Spain, Italy, Poland and Netherlands, allowed us to visualise the different trends. The decrease in science and engineering graduates (all tertiary levels) over the period 1998-2001 is clear for Germany and Netherlands, and in Italy for science graduates alone. The other countries show increased numbers of graduates, some with sharp rises (Poland). The breakdown by disciplinary areas shows that the physical sciences and mathematics are the most affected, other fields (life sciences and computer sciences) either being stable or increasing. At PhD level (examined for Germany, France and the UK) the trend is the same with decreasing numbers observed in Germany, which are confirmed by a graph showing the evolution of the number of all S&T graduates in this country between 1993 and 1996 that exhibits either a decrease (engineering) or flat curves. Comparisons are offered with science and engineering graduates for six other medium-sized countries: Austria, Finland, Hungary, Ireland, Norway, and Sweden. The results are very different with some important decreases (Hungary) and sharp rises (Ireland, Sweden) illustrating the contrasting situations in Europe due to different dynamics in the national economies. Two final diagrams show the total number of graduates (all disciplinary fields

---

[10] European Commission, Community Research, Key Figures 2003-2004, p.44

including humanities). There has been an increase in Europe with the important exceptions of Germany and the Netherlands. The curves for PhDs are slowly rising, showing no drastic change in the rate of ‘production’ over the years covered (1998-2001). Germany has the lead with two and a half times more ‘Doctors’ than France and the UK. There is a paradox in the German data: two times *less* university graduates than in France and the UK but a ratio of researchers to 1 000 workforce equivalent to one in France and slightly above one in the UK. Moreover, Germany has a share of population (aged 25-59) with upper secondary education of more than 80% (as in the UK, to be contrasted with only 64% for France and much less for the other southern Europe countries).

We have also studied national statistics on higher education for three countries: France, Germany and the UK. Those statistics provide the number of students entering an academic field at their entrance in the university system and on the successive diploma obtained by those who stayed in the system. Evidence of disinterest in all three countries as regards ‘classical’ fields such as mathematics and physical sciences (which includes physics and chemistry, among others) is very clear. Students’ interest has shifted to life sciences and computer sciences whereas engineering fluctuates. But the paradox is that the numbers of higher tertiary graduates are *increasing* at times when the numbers of lower graduates are diminishing. There is consequently a clear risk of a diminishing number of highly qualified tertiary graduates (PhDs) in the near future. Consequently, an episode of unemployment among qualified S&T people, which peaked in 1997, occurred at a time of rising “production” of graduates with, as a consequence, a decrease in newly enrolled students. Students entering universities can react quickly to changes in the work market by shifting to another more promising sector, but this is not the case for advanced graduates who are stuck in their speciality after several years of study and may fall victim to an unfavourable economical cycle situation.

This shows how important it is to provide counter cycle measures to prevent the wasting of human capital in those situations.

The number of S&E graduates in Europe is higher than in the US and Japan. But the proportion of people aged 25-64 with a university degree is much lower in Europe than in Japan and the US. Europe’s strength is in its younger fraction of the population trained in S&T. Europe would be catching up with the US and Japan in terms of researchers by 1 000 workers if employment in R&D was available for young people, if the number of those who choose to study S&T is not allowed to diminish, if more women are involved in R&D, and if the southern countries accelerate their S&T development because it is there that the human potential for growth mainly lies. In particular, educational achievement and the rapid reduction in unacceptable early drop-out rates in many European countries will be key policy objectives to broaden the qualifications pool for S&T professions.

As most of the employment for researchers is created by industry, better conditions for the development of research by the private sector have to be reinforced in Europe, if the Lisbon and Barcelona goals are to be met. On the other hand, the level of public funding per researcher in Europe is clearly well below that in the US. It is not surprising, therefore, that the number of European researchers, namely in the public sector, does not translate into the same level of working conditions and, consequently, of results. The conditions and prospects for employment by the public sector (by universities, public research centres or other publicly funded research institutions) should be recognised as critical for the EU strategy. New human resources for S&T will not be attracted at the required level unless governments translate their own political goals urgently into new research jobs and better career perspectives. In periods of economic slow-down, this conclusion is even stronger.

One final comment about the statistical evidence: this preliminary report does not include yet detailed national statistics provided by national countries to the HLG, as most of that data had not been made available when the present version was completed. However, the final published version of the report will consider any new available evidence.

The 'crisis' in the production of human resources for R&D

Science and technology activities are based upon qualified human resources. According to OECD data, technical and scientific jobs represent between 20 and 35% of total employment in Europe[11].

In 2001, the number of *researchers* per 1 000 of the workforce (in full-time equivalent, FTE) was 5.7 for the EU-15. Finland tops the list with 13.77 (3.5 for acceding countries). Between 1995 and 2001, on average the growth rate was 2.6% for the EU-15 and 2.1% for acceding countries. For a majority of countries, employment in R&D grew faster than total employment in the period 1995-2002, more than 5% a year in Spain, Norway and Ireland. In the 1990s, the number of researchers per 1 000 workforce increased by more than 100% in Greece and Portugal and by over 50% in Austria, Finland, Denmark, Sweden and Belgium. There are large individual differences between the European countries[12].

These figures should be compared to a value of 9.14 researchers per 1 000 of the workforce (FTE) for Japan and 8.08 for the USA. Only some countries in Europe (Finland, Sweden, Norway) reach that standard and the most populated ones show much lower figures (Germany 6.55, UK 5.49, France 6.55). Consequently, there is an important margin of progress possible in Europe to increase human resources in R&D, namely in the central and southern European countries.

The Lisbon and Barcelona EU objectives of attaining 3% of GDP for R&D (from the present level of around 2%) will roughly require a minimum level of eight researchers per thousand of the workforce. However, this objective will not be attainable within a reasonable time (and certainly not in 2010, as targeted by the EU summits) should the present trends continue unchanged. On the other hand, a clear departure from stagnation or reduced growth rates in R&D employment will require important changes in the most relevant factors affecting this outcome.

To sustain and increase the work force in R&D, an analysis of the social, economical and cultural parameters involved is necessary and will be undertaken in the following chapters. This involves, namely, education and science policies and, specifically, R&D job creation in the public as well as in the private sector, in view of the ageing of the population and the potential migratory flows to or from Europe. Two questions arise:

---

[11] OECD Science and Technology Scoreboard 2003, p. 56-57

[12] European Commission, Community research, Key Figures 2003-2004, p.44

- Although the overall number of graduates in Europe qualified for work in S&T has been growing moderately in recent years, is there a risk of stagnation or even of decrease?

- How can a *significant* increase in the number of people *employed* in S&T be made in order to achieve the Lisbon and Barcelona objectives and match the standards seen in Japan, the US, or in some northern European countries?

2.1 Alarming signals

For several years now there have been warnings from universities that the number of students has been declining sharply in some disciplinary areas, namely physics, chemistry and mathematics.

In some countries, there seems to be increasingly pronounced evidence of a decline in the interest of young people to study science and retain the option of pursuing science-related careers. However, 30 years ago, Ormerod and Duckworth (1975)[13] were already reviewing pupils' attitudes to science in the UK, as follows:

> *"In 1965, a thorough inquiry began into the flow of students of science and technology in higher education. The final report laid particular emphasis on the phenomenon which had become known as the 'swing from science'. Several explanations were suggested for the swing, among them a lessening interest in a science and a disaffection with science and technology amongst students."*

In the past decade, there seems to have been a growing perception that the problem has become more acute in some countries. This has been linked to the liberalisation of the system of subject choice in schools in many countries and the increasing variety of courses being offered at university.

For instance, in the UK and Ireland the number and proportion of young people, respectively, choosing physics or chemistry has declined steadily during the 1990s, while biology has, at best, managed to maintain steady numbers. The problem is equally pronounced in France, the Netherlands, Norway, Denmark and Italy. Officially, out of the EU-25 countries, only Greece and the Flemish part of Belgium report that they do not face a diminishing trend in the number of students choosing to study science in schools[14].

Although the overall number of SET students in the UK is relatively high, and growing, the numbers of students choosing to study mathematics, physics, chemistry and many branches of engineering are falling significantly. For example, the number of students studying A-level physics in England fell by 21% between 1991 and 2000. Unchecked, these trends could result in a serious shortage of scientists and engineers, both for R&D and for other areas of the economy. Graduates in mathematics, engineering and the physical sciences are commanding higher, and faster increasing, salaries than most other graduates (including biological science graduates). Given the increasing importance of

---

[13] Ormerod, M. B. and Duckworth, D. (1975), "Pupils' attitudes to science" (Slough: NFER)

[14] Osborne, J., Simon, S. and Collins, S. (2003), "Attitudes towards science: a review of the literature and its implications", *International Journal of Science Education*, 25(9), 1049-1079

interdisciplinary research, these trends in engineering and the physical sciences could also affect research in other areas.

Figure 1. **Numbers of students examined in physics, chemistry and biology from 1990 to 2000 in England and Wales at A-level. (UK Examination Boards and HMSO)**

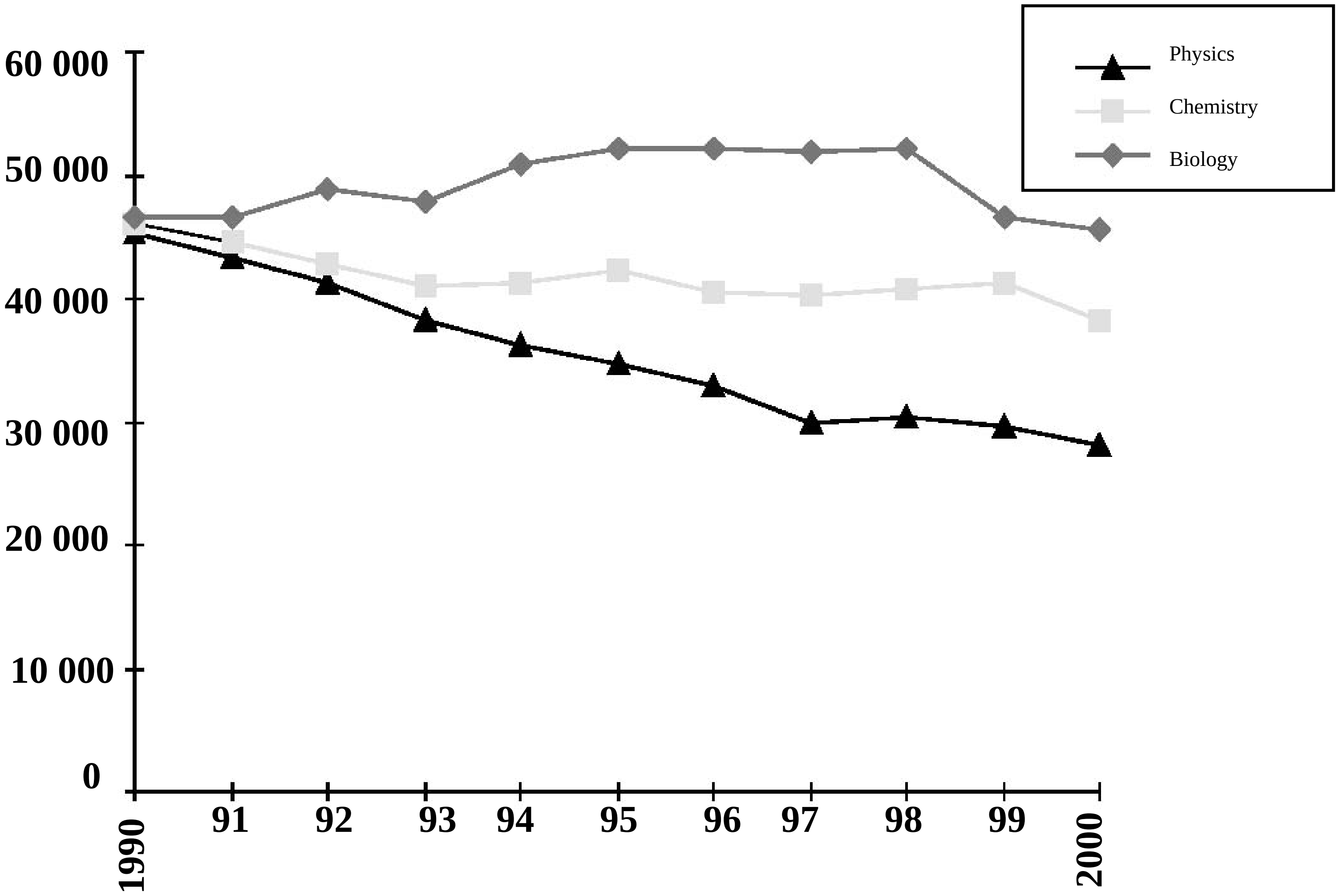
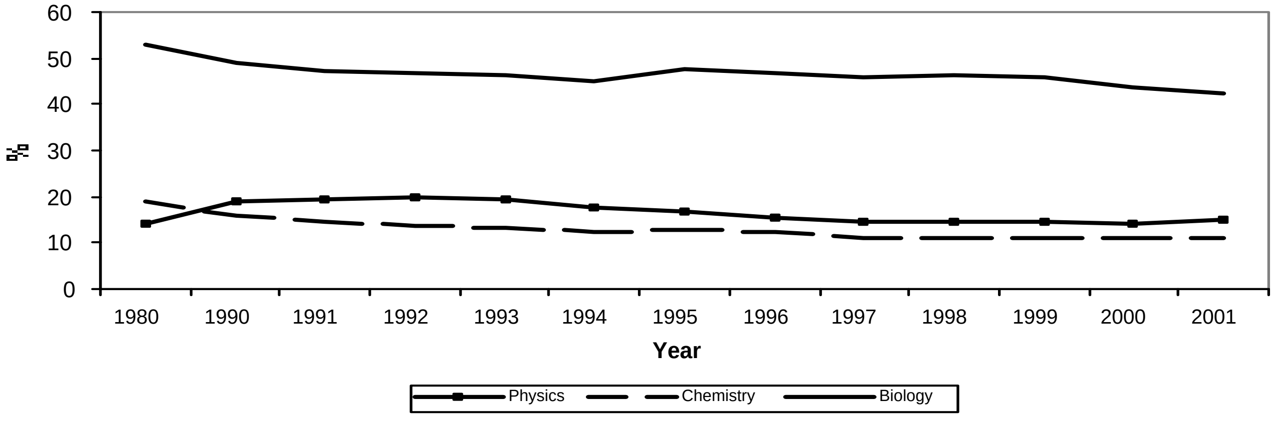


Figure 2. **Uptake of physics, chemistry and biology at upper secondary level in Ireland (1980-2001).[4] (Yearly Statistical Reports, Department of Education and Science, Ireland)**



In France, the decrease in student *enrolment* numbers is pronounced in some scientific disciplines, but not in others (computer science), and the number of *graduates* from engineering schools (Grandes Ecoles and many others) has *increased* from 12 000 in 1993 to 50 000 in 2000. In particular, this concerns the first years in university. For instance, at the University of Strasbourg, from 1995/1996 to 1999/2000 the *decrease* in the *enrolment* of students reached:
47% in physics and chemistry
20% in mathematics
29% in life sciences
18% in applied mathematics and social sciences
41% in industrial technology
47% in earth sciences

In Germany, from 1990 to 1994, the number of students taking first-year chemistry declined by 56% and the number of students in physics has been cut by a third over that period. In the Netherlands, between 1989 and 1994, the number of first-year university students has diminished by 38% for chemistry and by 20% for computer science and physics[15].

The problem is discussed in detail in the three case studies (France, Germany, UK) below. This trend of diminishing attendance at some types of academic classes should be compared with the number of *graduates*. Because more and more people have access to university, there have been important changes during the first years at university as regards reorientation and dropping out. As universities also produce teachers, we must also take into account the problem of the attractiveness of the teaching profession both from the point of view of salaries and working conditions. Some of these drop-outs may have turned to a more technical career and received another type of training rather than that at university. This is rather difficult to follow because of the complexity of the offers available in education.

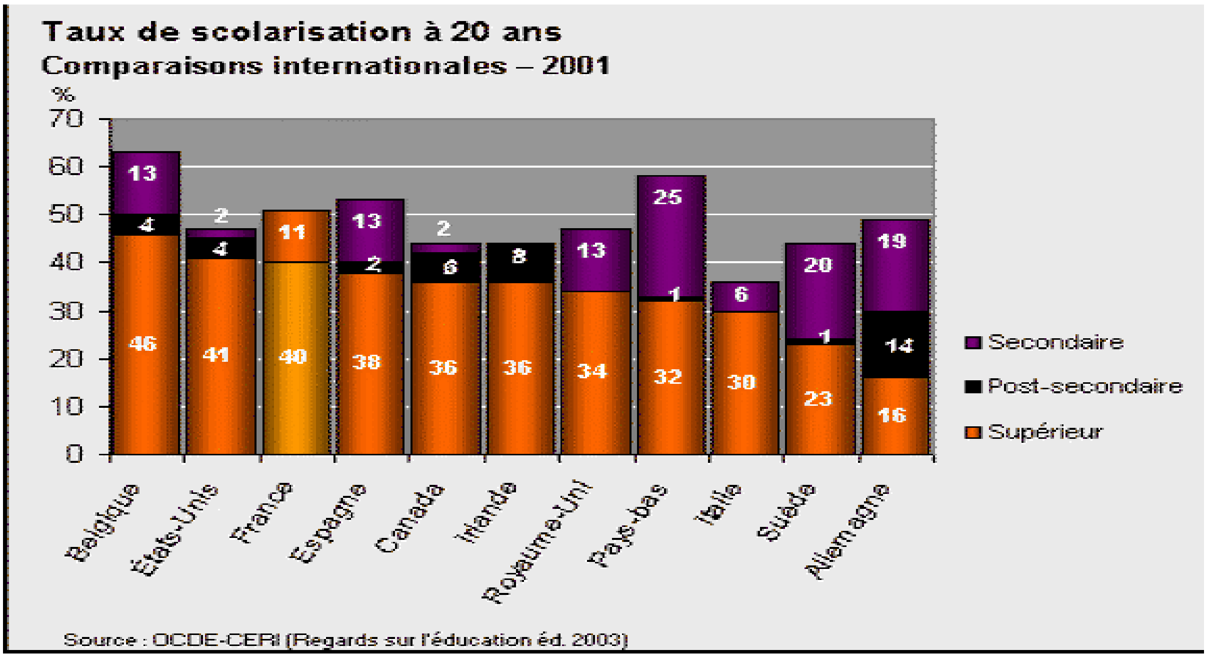
2.2 The number of tertiary S&T graduates in Europe according to the OECD statistics

The notion of ‘graduates’ should be linked to the structure of the education system in different countries. R&D needs not only researchers – people with PhD degrees or the equivalent – but also engineers and technicians with lower university degrees or with diplomas from specialised schools, for example in engineering, agriculture or medicine. The hierarchical structure of teaching from secondary degree to university level is usually rather complex, and international comparisons may be difficult to establish even when protocols have been designed (the Canberra Manual) to facilitate the collection of data on an international basis (Eurostat, OECD). For instance, Germany has a lot fewer university graduates than the UK or France although it boosts two and a half more ‘doctors’. At the same time, Germany has about the same number of researchers by 1 000 of the workforce as France and the UK, as mentioned above.

---

[15] Those data are extracted from the report “Désaffection des étudiants pour les études scientifiques” by Guy Ourisson, March 2002; see also the report by Maurice Porchet “Les jeunes et les études scientifiques”, March 2002 . Both reports are available at www.education.gouv.fr

The diagram below, extracted from a French document[16], exhibits the differences between European countries and shows that the number of students in what is defined elsewhere as tertiary education is less in Germany than in other countries.



Source : OCDE-CERI (Regards sur l'éducation éd. 2003)

Consequently, comparison of *absolute values* may be difficult from country to country within a category of S&T personnel. But *trends* may be evaluated within a fixed scheme. We have used the OECD statistics[17] for the period 1998-2001 to follow the evolution of graduates from year to year. A change in statistical methods in 1997 does not allow for comparisons with the period 1990-1996, although for those years the series are complete for a few countries.

Figure 3 represents the evolution of science graduates from 1998 to 2001, as defined by the OECD for the most populated countries in Europe. 'Science' graduates are the sum of the graduates in mathematics and statistics, life sciences, computing, and physical sciences at the tertiary level. There is a rise in the number of graduates in the UK and France and also in Poland and Spain, but a decrease in Germany and the Netherlands.

Figure 4 represents the evolution of engineering graduates during the same period. The numbers are very similar in 1998 for the UK, France and Germany but decrease quite clearly for Germany and are stable or increase for all the other countries.

Figures 5, 6 and 7 show the evolution of graduates by disciplinary areas for Germany, France (data incomplete) and the UK. There is a sharp decline for physical sciences and mathematics in Germany but not in computing or life sciences. Graduates studying physical sciences increase sharply in the UK after 2000.

---

[16] "Les grands chiffres 2002-2003", Ministère de l'Education Nationale, France

[17] We sincerely thank Ms. Laudeline Auriol from OECD for communicating the listings of data from which we have drawn the figures 3 to 15 and the document DSTI/EAS/STP/NESTI (2003)9 of February 12 2003, entitled "The supply of HRST in OECD countries: stocks, flows and characteristics of tertiary-level graduates"

The next three figures 8, 9 and 10, represent the evolution of the number of PhD or equivalent for the three countries. Once again the physical sciences are declining in Germany whereas they seem to be booming in the UK and are well sustained in France. (ARP means Advanced Research Programmes)

The series of data for the period 1993-1996, which is complete for Germany (Figure 11), shows a decrease in engineering graduates but stable numbers for mathematics, computing and natural sciences. If there is a 'crisis' in this country it would appear it can be dated from the years 1997-1998.

An examination of a selection of other countries shows very different behaviour over the years 1998-2001: there is a sharp rise in engineering graduates in Sweden and a sharp decrease in Hungary (Figure 12). There is a pronounced increase in science graduates in Ireland (which goes along with UK data), a less pronounced rise for Sweden, and a decrease, which may have stabilised, for Austria and Hungary (Figure 13).

The last two OECD data-derived figures (Figures 14 and 15) show the overall number of graduates in all fields (including social sciences and humanities) and the PhDs in all fields.

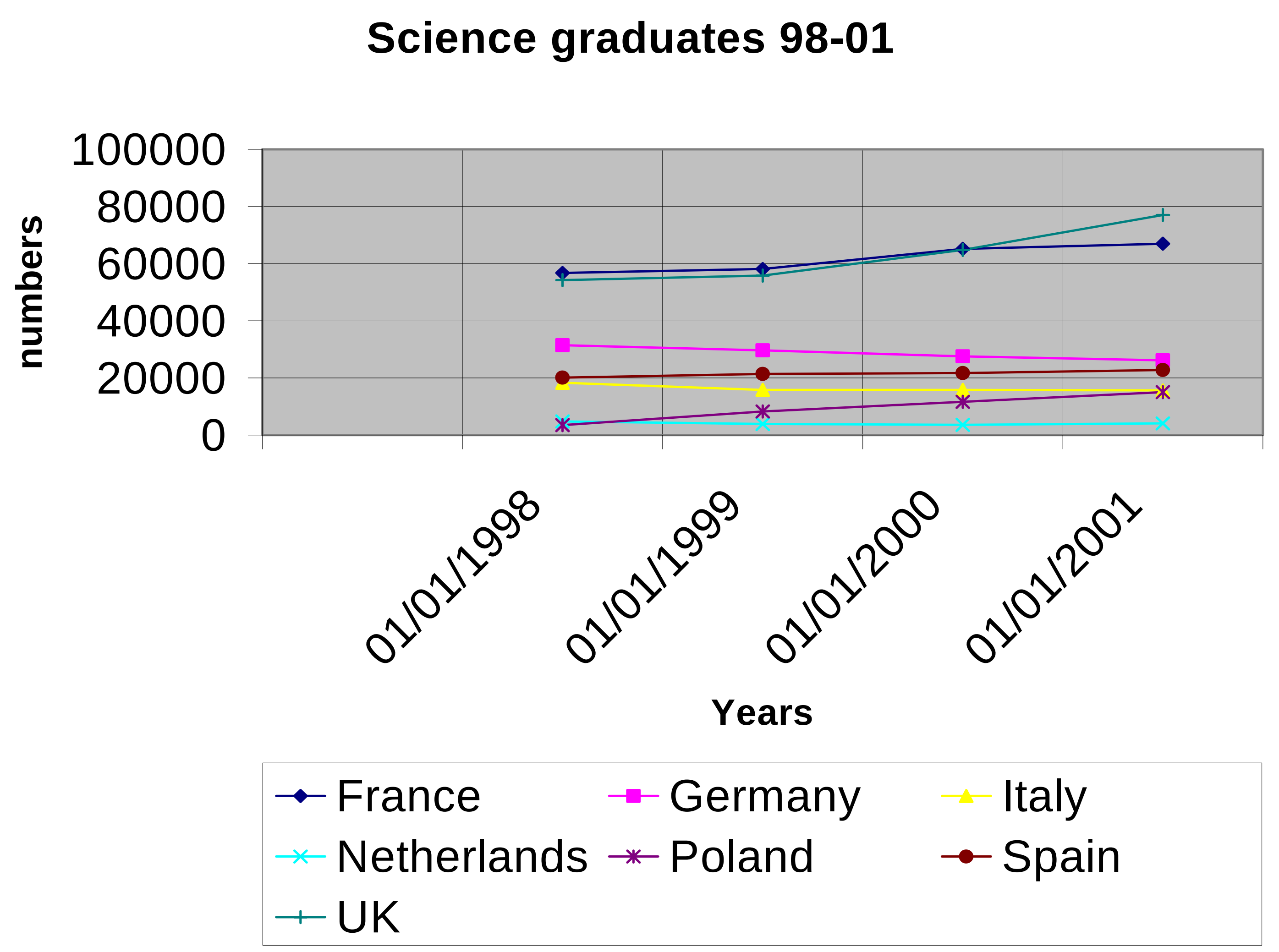


Figure 3. Science graduates 1998-2001. (Source: OECD)

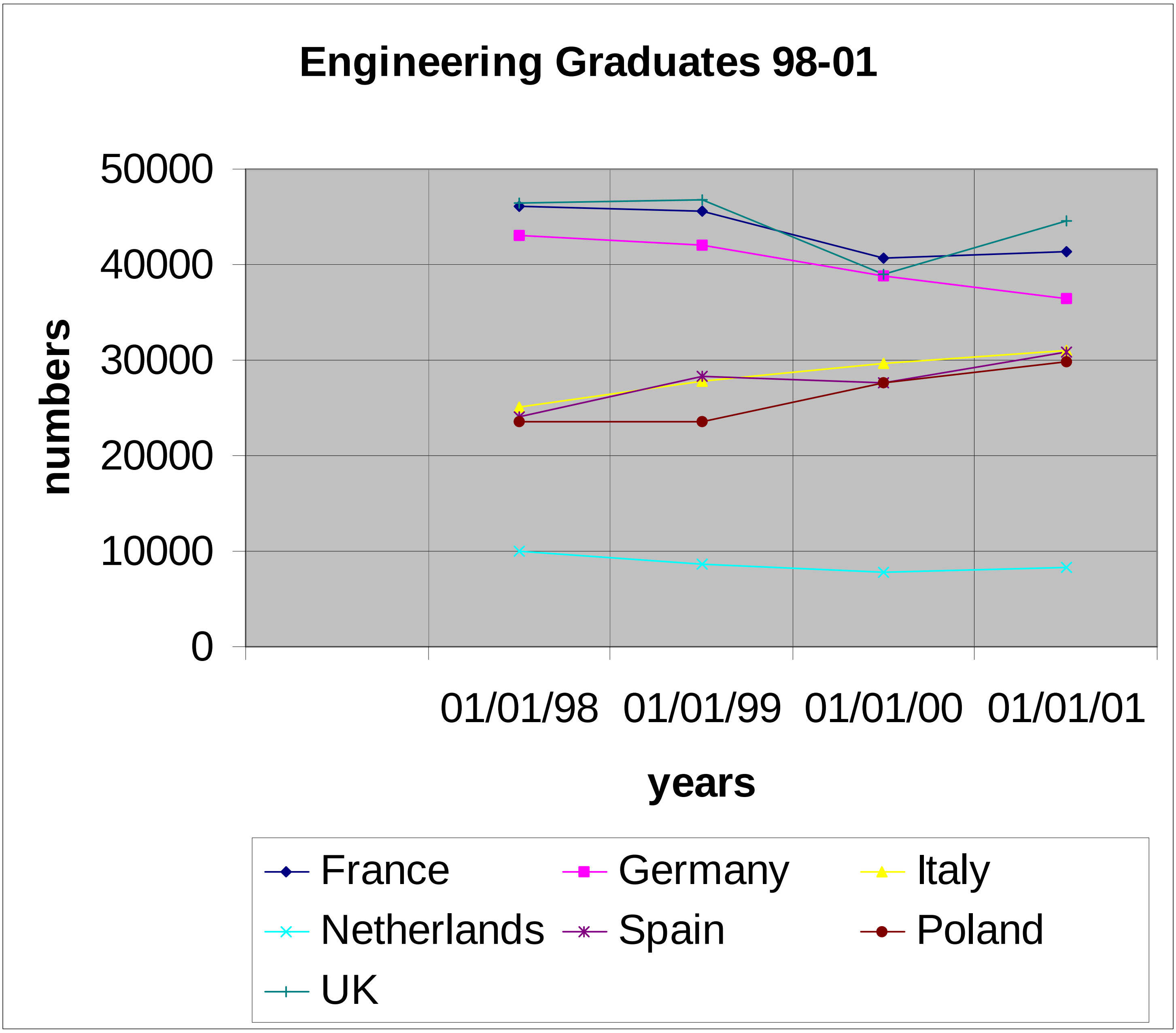


Figure 4. **Engineering graduates 1998-2001. (Source: OECD)**

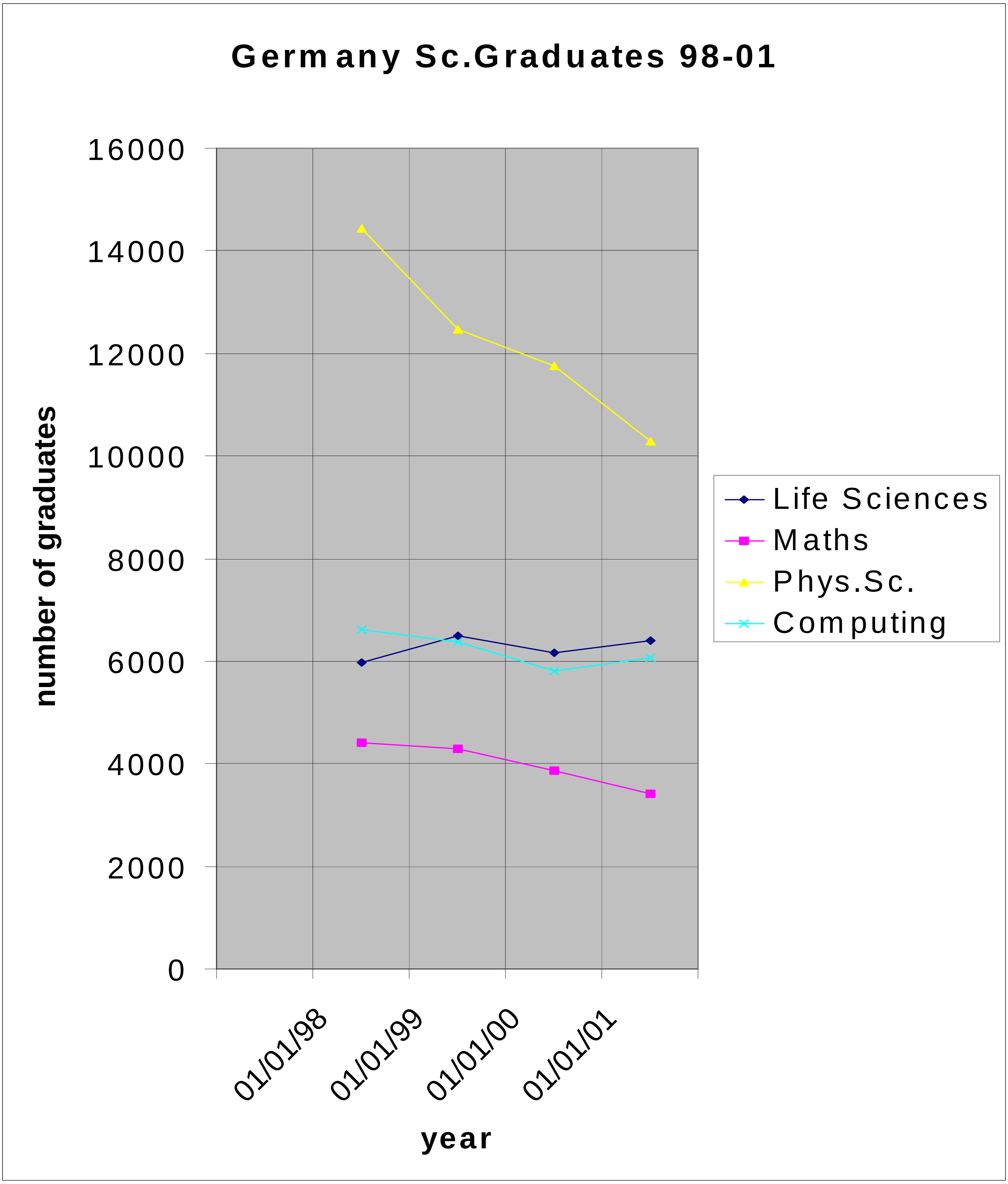


Figure 5. Science graduates in Germany, by disciplinary sectors. (Source: OECD)

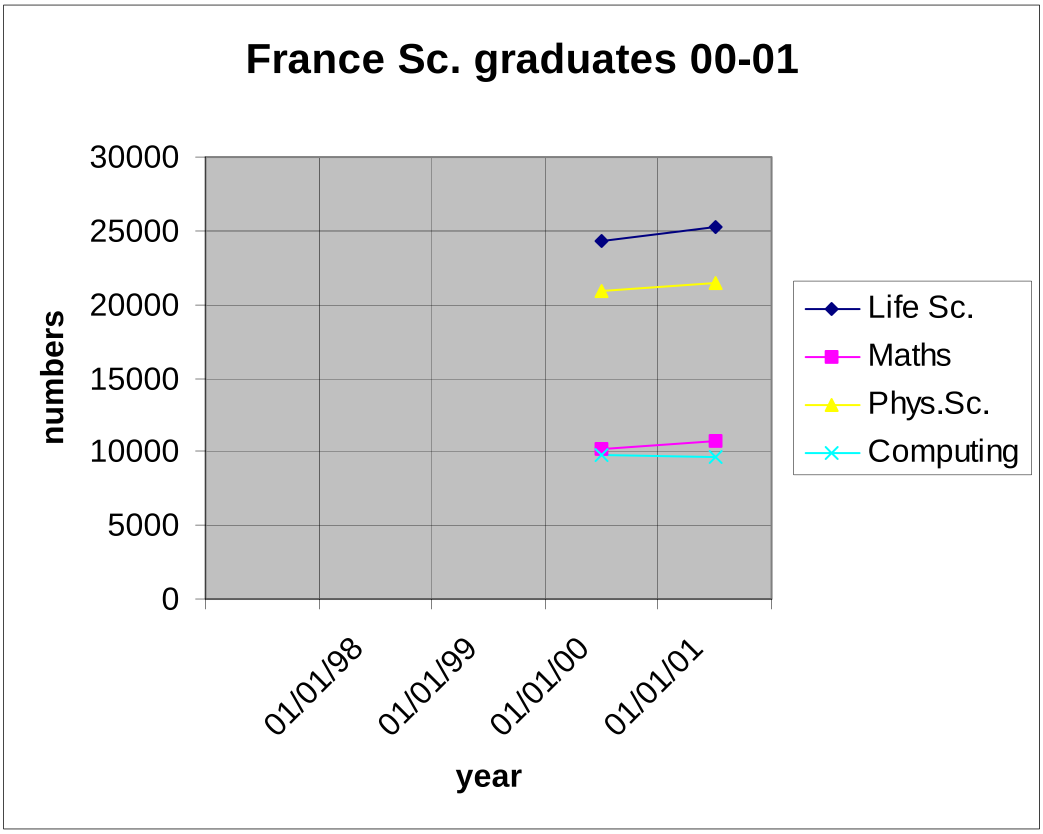


Figure 6. **Science graduates in France 2000-2001. (Source: OECD)**

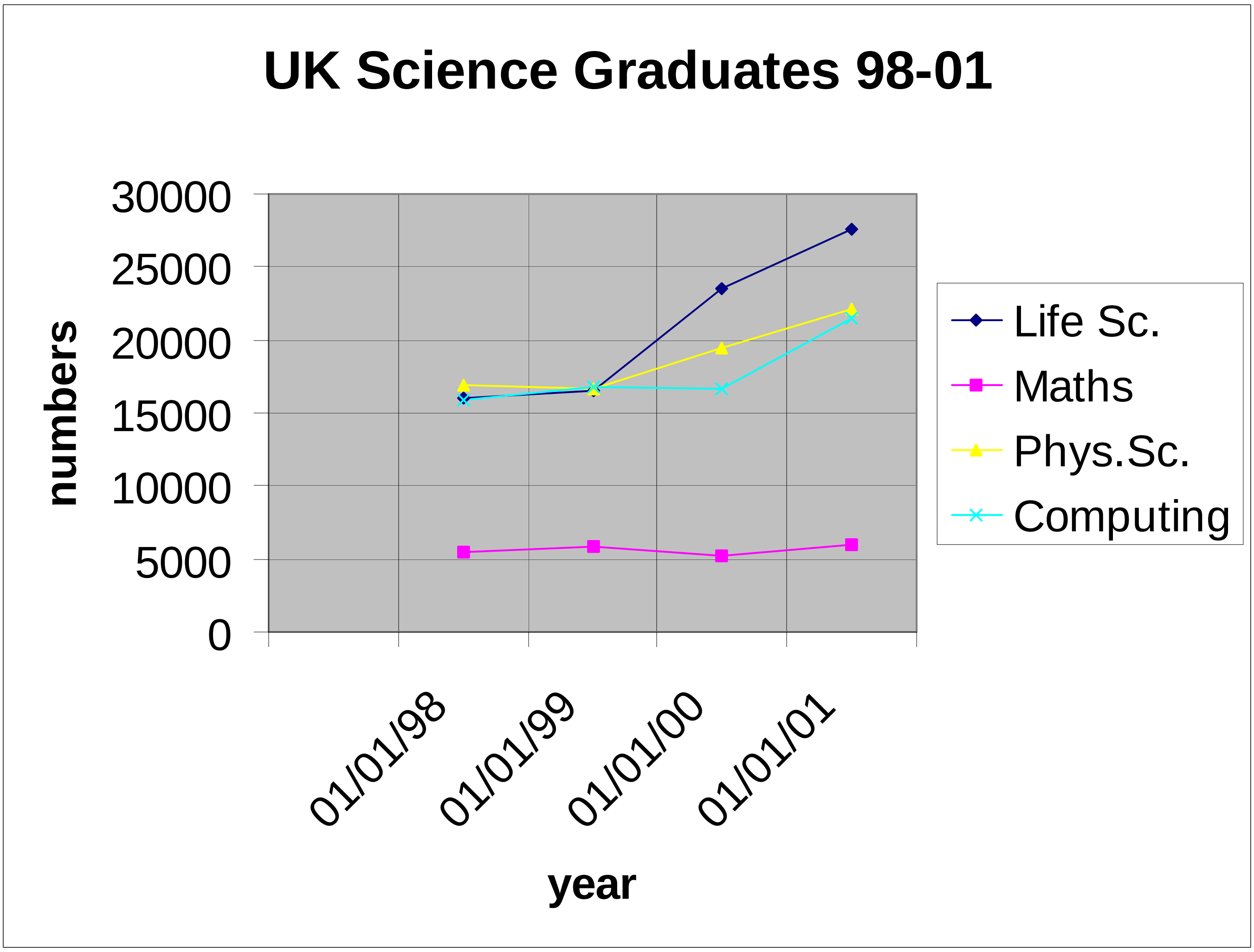


Figure 7. Science graduates in the UK, by disciplinary sectors. (Source: OECD)

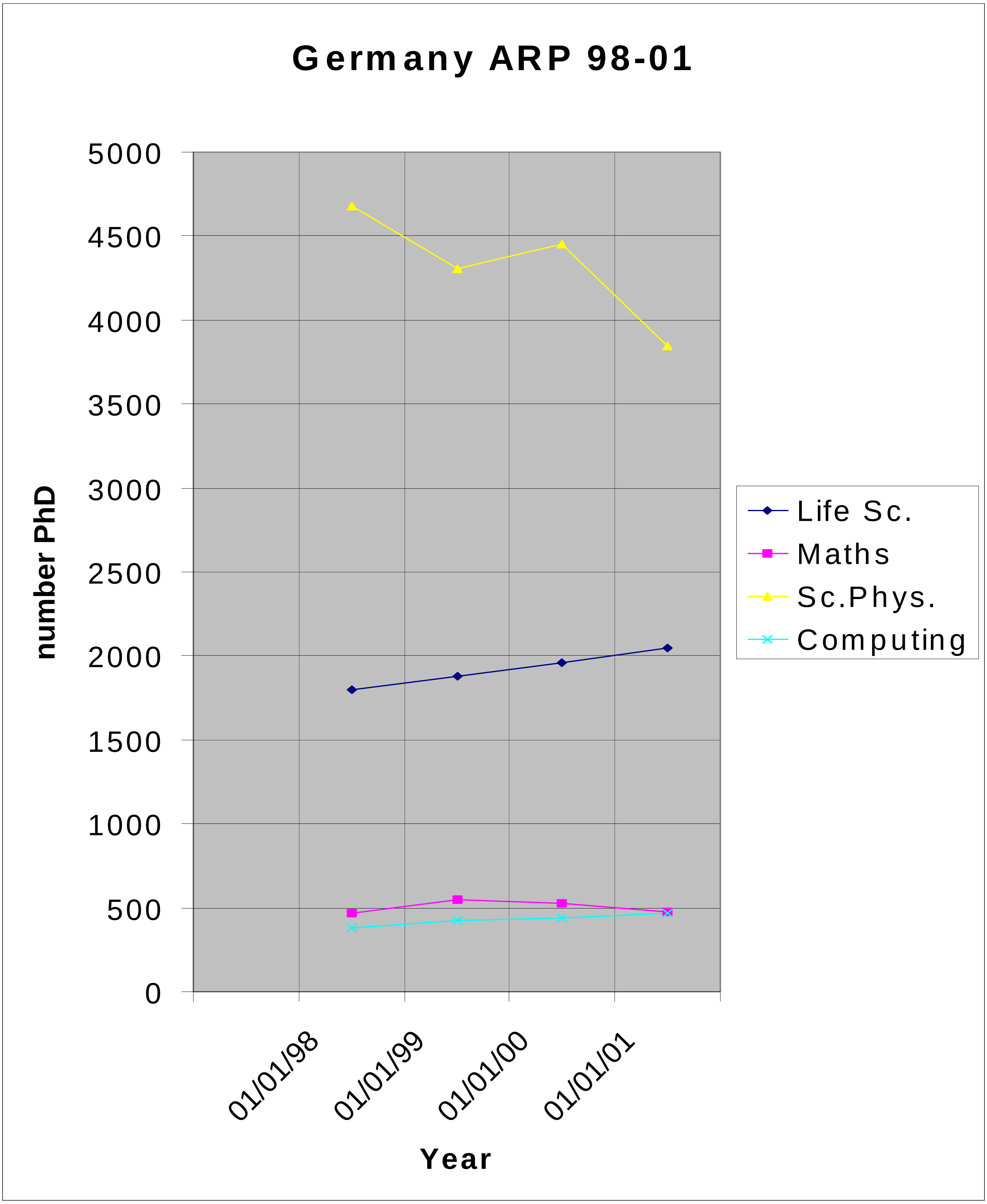


Figure 8. Graduates in Germany in advanced research projects, by disciplinary sectors. (Source: OECD)

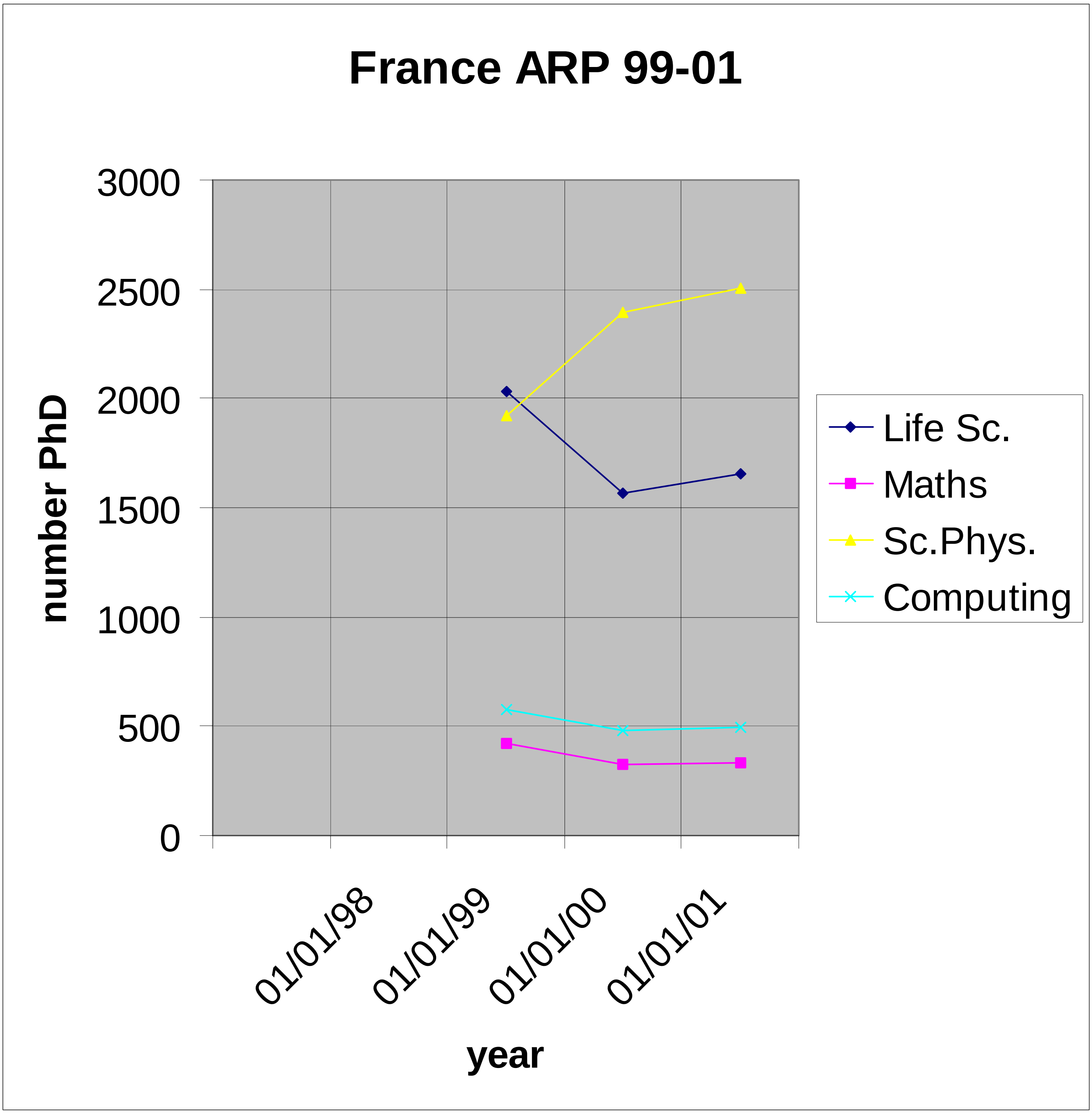


Figure 9. Graduates in France in advanced research projects, by disciplinary sectors. (Source: OECD)

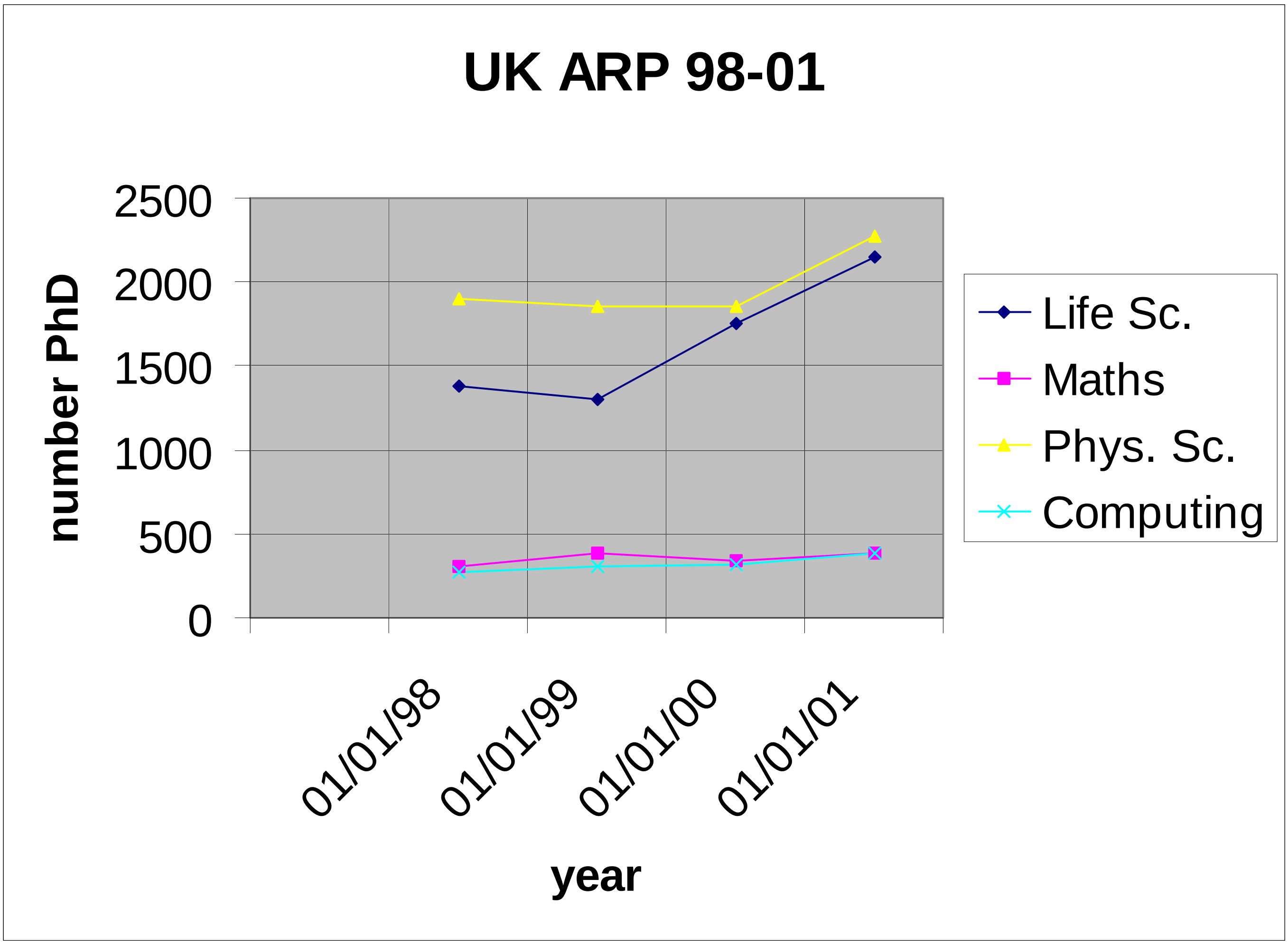


Figure 10. Graduates in the UK in advanced research projects, by disciplinary sectors. (Source: OECD)

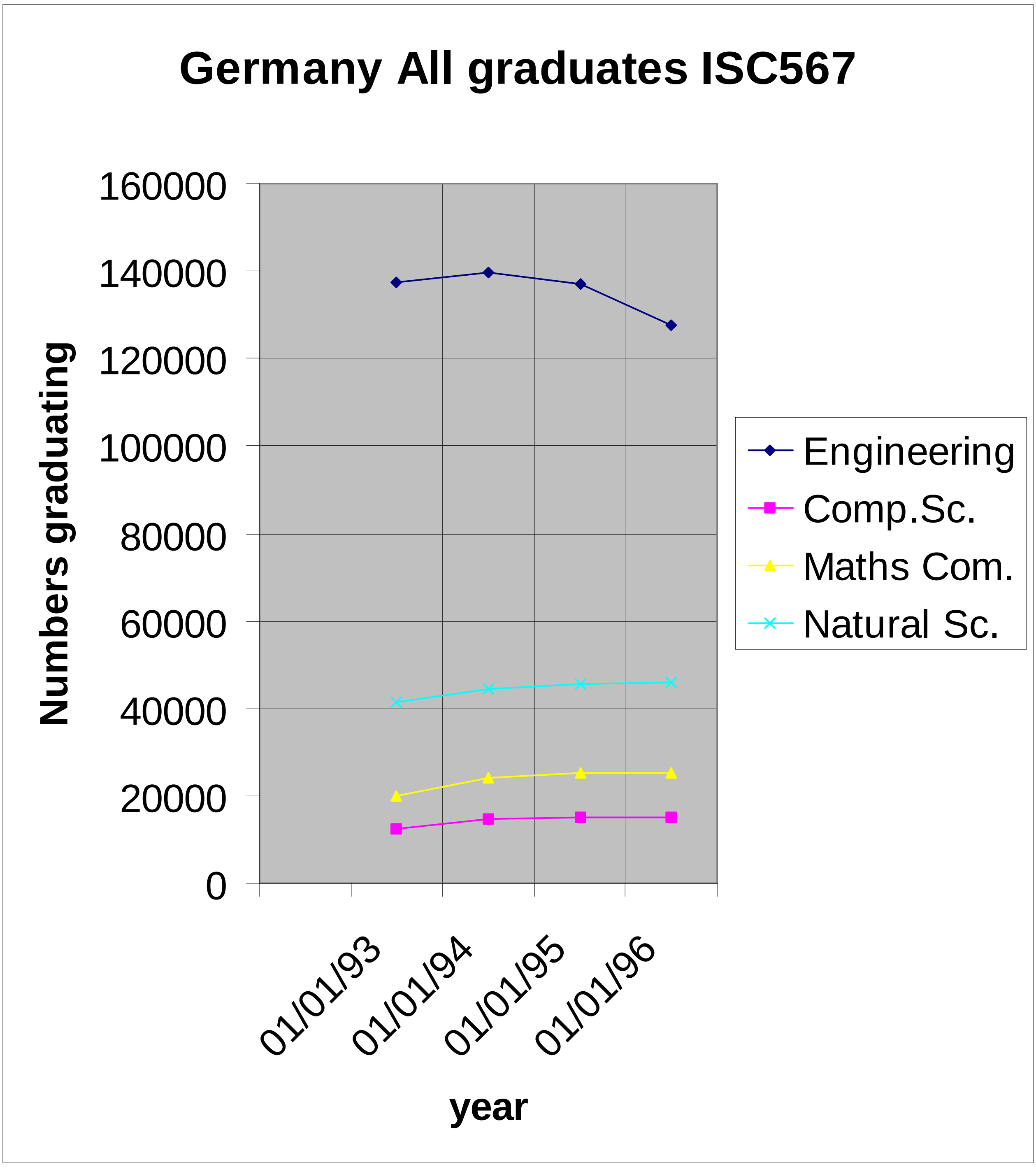


Figure 11. Graduates in Germany (medium and advanced studies), 1993-1996, by disciplinary fields. (Source: OECD)

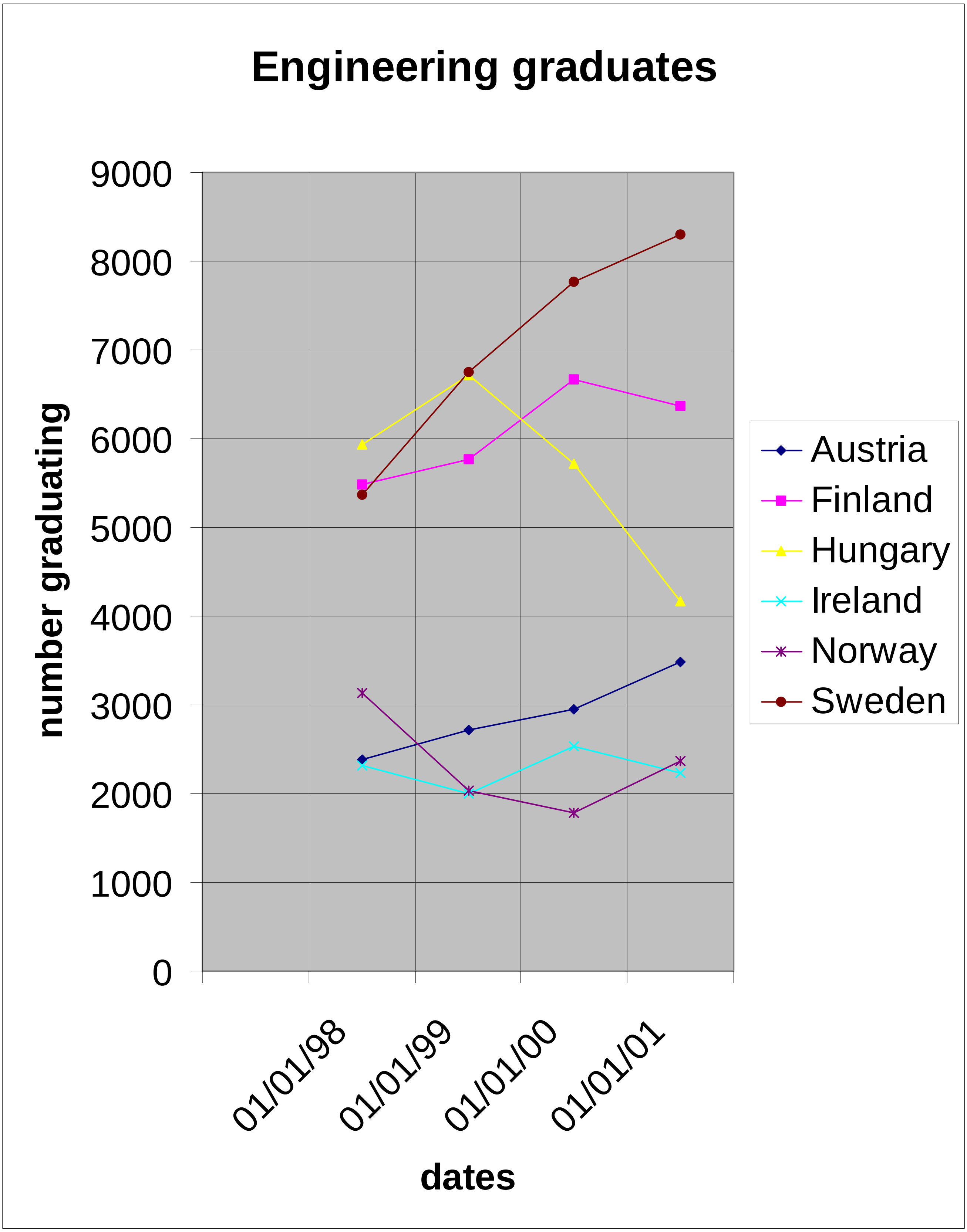


Figure 12. **Engineering graduates, 1998-2001, for medium-sized countries. (Source: OECD)**

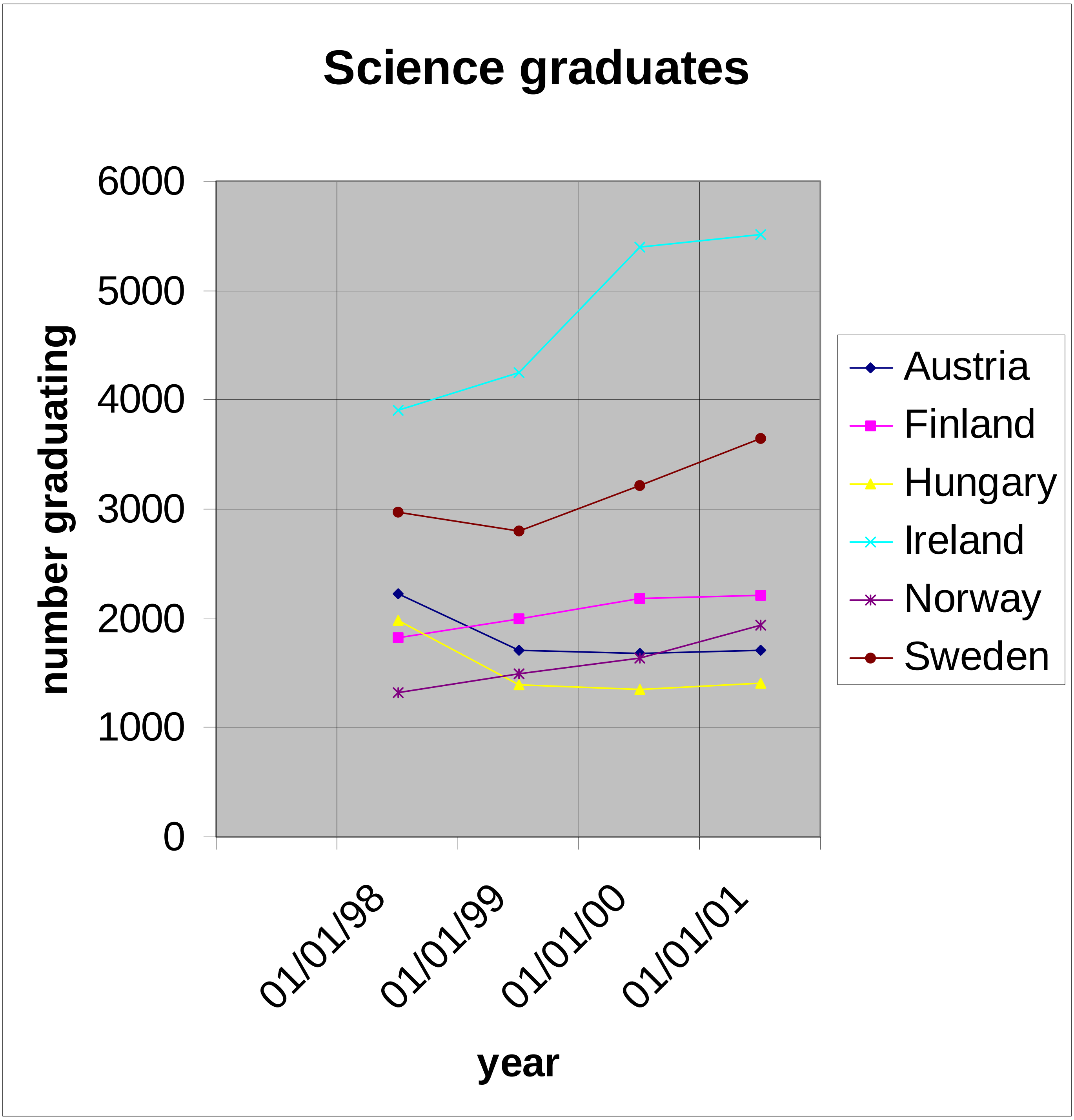


Figure 13. Science graduates, 1998-2001, for medium-sized countries. (Source: OECD)

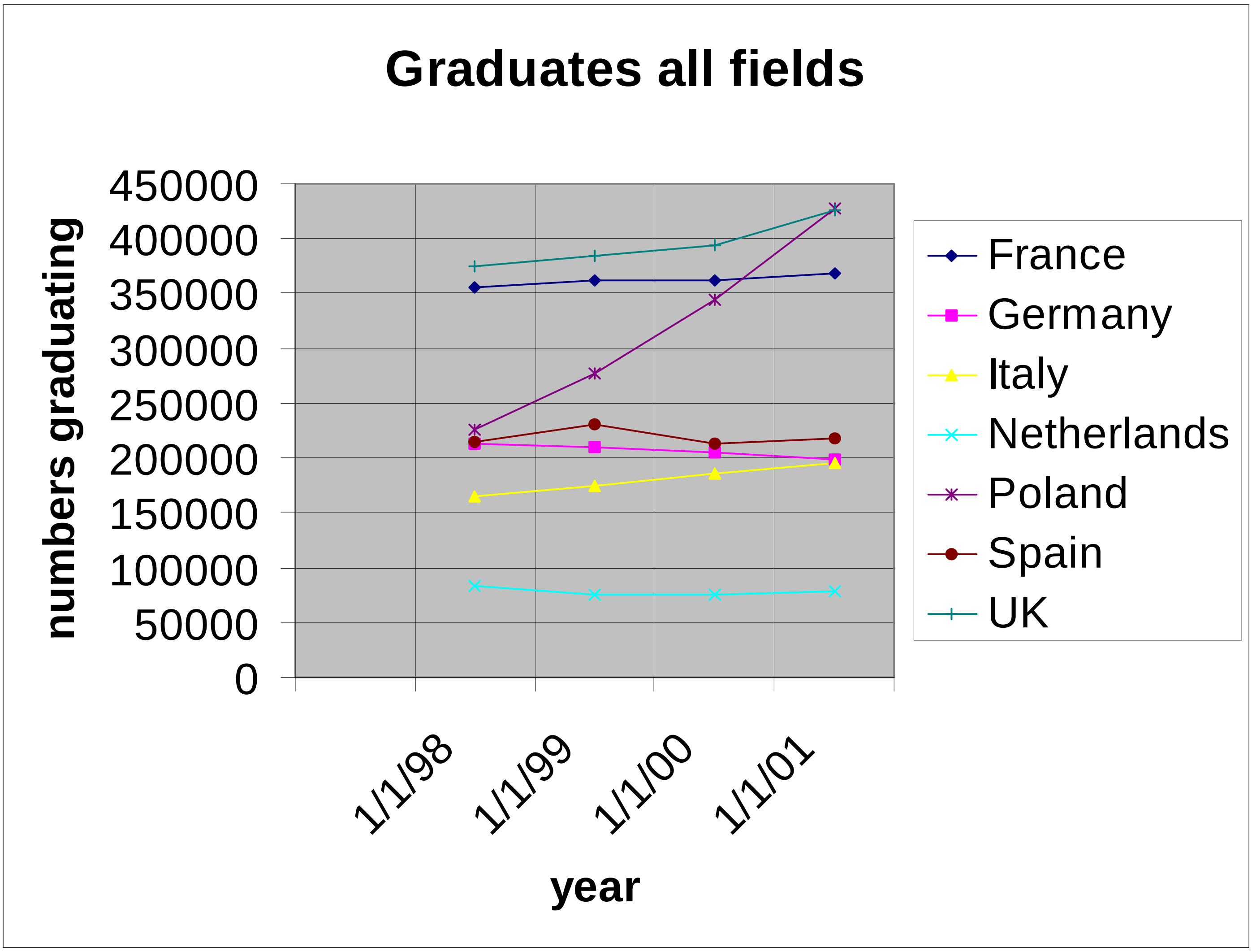


Figure 14. **Number of graduates (all fields). (Source: OECD)**

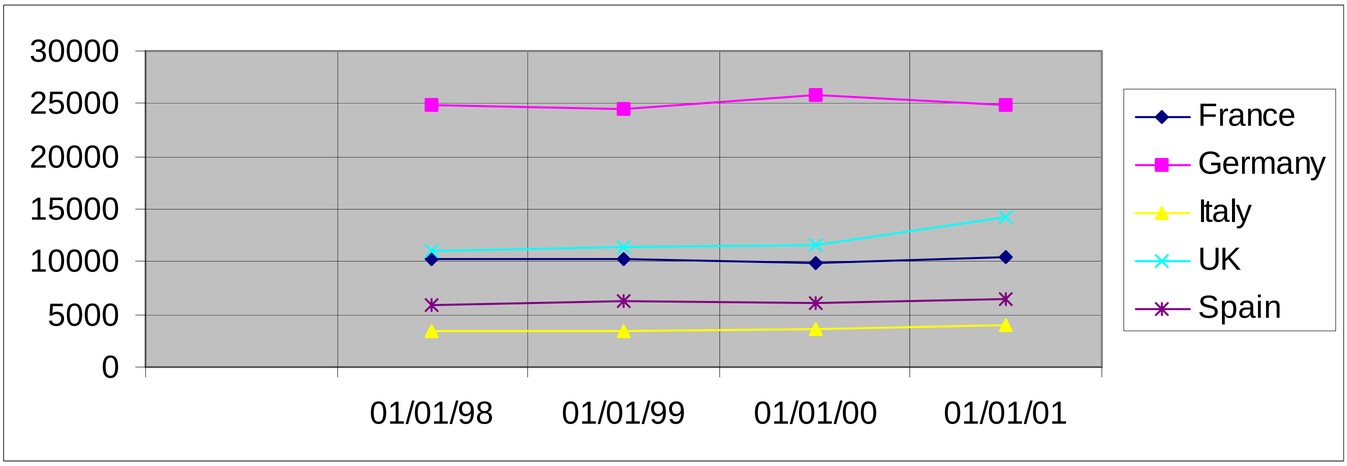


Figure 15. **Number of PhDs or equivalent (all fields). (Source: OECD)**

2.3 Case study: France

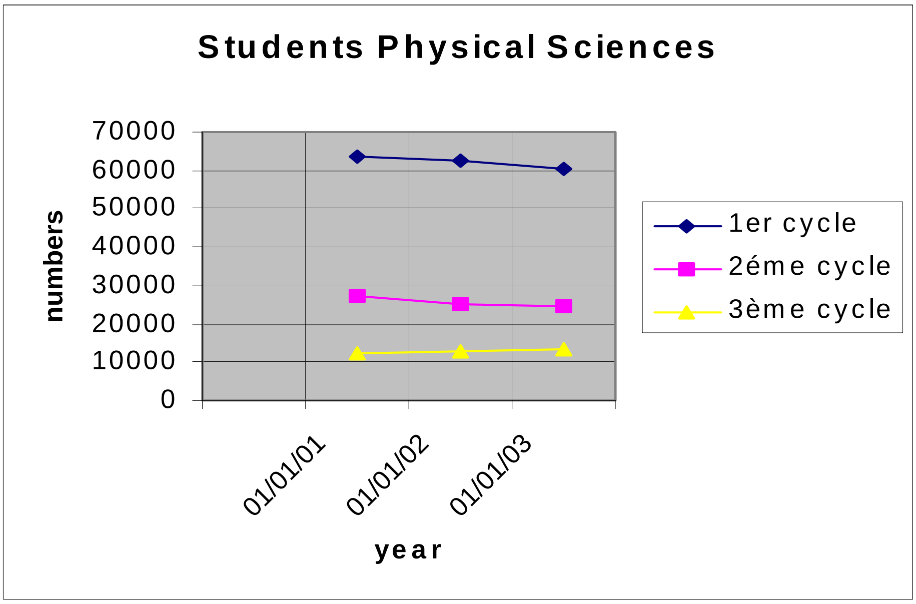
French statistics show a near 60% increase in the student population between 1980-1981 and 1995-1996, but the total number of students has been stable since then and, in fact, has declined slightly. Large differences can be observed between the student population in the first and second cycle at French universities. There is a loss of 40% for the physical sciences compared to a loss of only 20% for the life sciences[18]. Figure 16 represents the level of enrolment in French universities over the last three years 2001, 2002, 2003, across the three cycles in French universities (the third one being doctorate level and implying some research). Besides the diminution mentioned above in the level of enrolment between the first and second cycles, a *decrease* can be seen in the level of enrolment in the first cycle for physical sciences of 5% and of 10% for life sciences and, in the second cycle, of 10% and 2% respectively. However, there is an *increase* at the third-cycle level (the important cycle for high-level R&D personnel) of +8% for physical sciences and +38% for life sciences, whereas engineering enrolment is growing by +12% and third-cycle engineering by +19%. It seems that many new entrants at university try a certain type of study and then drop out. It will be important to work on that fraction of students to keep them focused on the prospect of a scientific career. There may be a slight demographic effect as the total number of new entrants in the French university system changed by -5% between 2001-2002 (294 073 in 2001, 279 132 in 2002 and 281 480 in 2003).

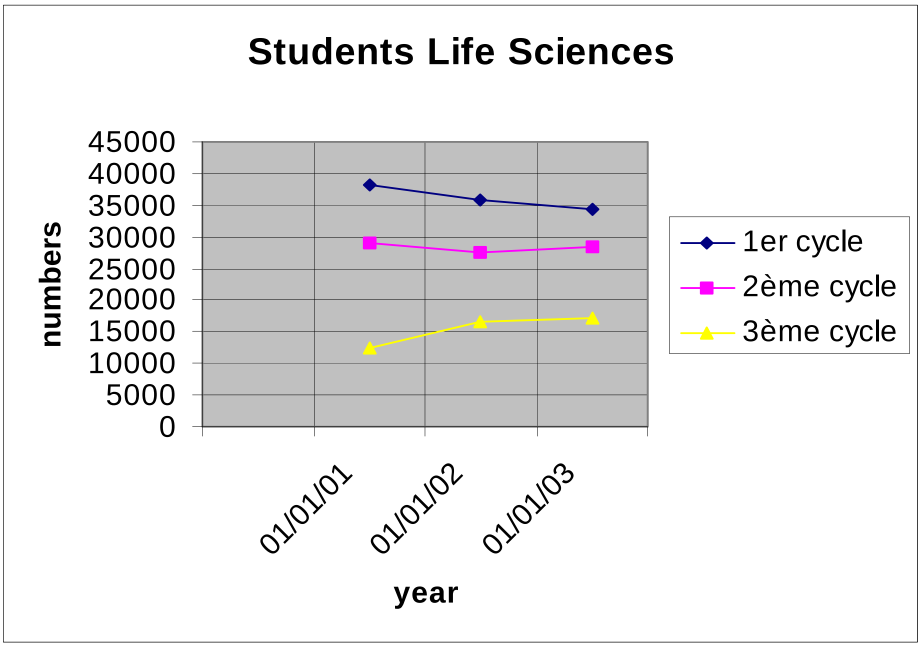
The number and categories of the degrees granted in the science field is represented in Figure 17 for 1999-2001. Graduates from the two first years corresponding to a degree called DEUG (Diplôme d'Etudes Universitaires Générales) have been falling by 8.5%. Second-cycle graduates (Maîtrise) have decreased by 5%. But the number of third-cycle diplomas awarded, such as the very popular DESS (Diplômes d'Etudes Supérieures Spécialisées), has increased by +41%, as has the older DEA (Diplôme d'Etudes Approfondies) (+8%), while the doctorate (PhD) remains stable. This confirms the trends shown by enrolment numbers: there are more and more students with a *tertiary* formation in science and engineering appropriate to work in R&D. However, the decline in the number of science students graduating in the first two cycles of university may be a problem for the recruitment of *teachers* in the future. In addition, the opposite trends observed between enrolment and graduates may be connected to the onset of an economical cycle (see the case study for Germany).

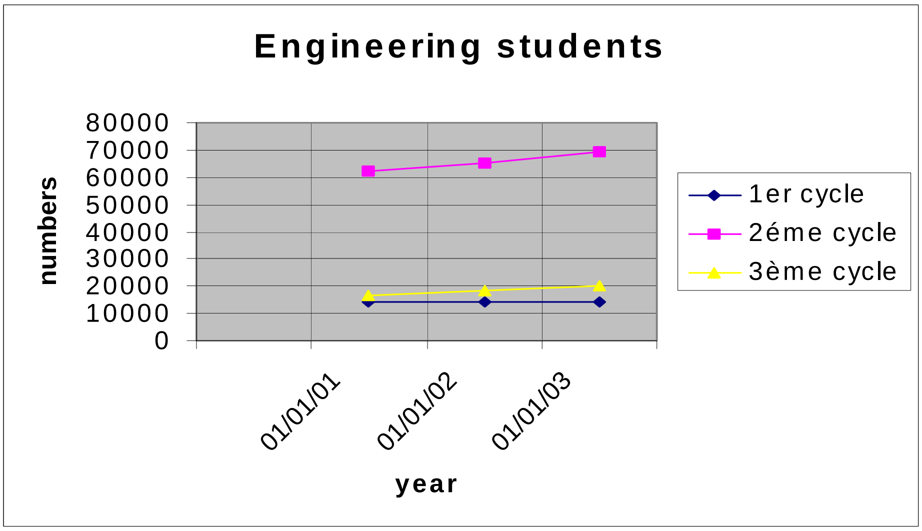
---

[18] "Repères et références statistiques" (RERS) 2001, 2002, 2003, Ministère de l'Education Nationale et de la Recherche, Paris

Figure 16. Enrolment of university students in France 2001-2003.







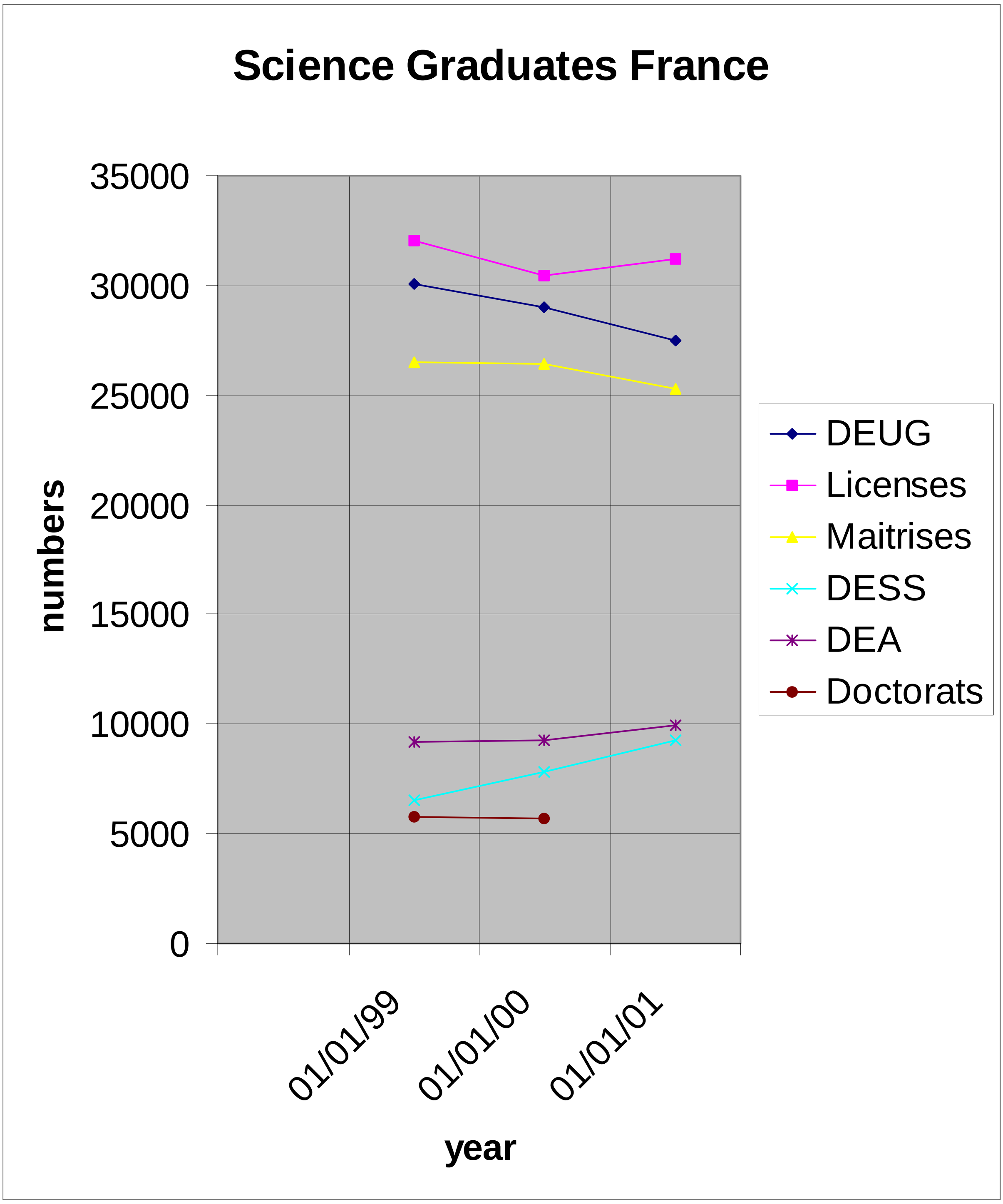


Figure 17. **Science graduates from French universities, first, second and third cycle 1999-2001.**

2.4 Case study: Germany

Higher education in Germany depends on several types of institutions, the most important being the universities (338 984 students enrolled in 2002/2003, an increase of 15% with respect to 2001/2002) and the *Fachhochschulen* (specialised colleges of higher education (126 587 students enrolled in 2002/2003, an increase of 7% with respect to 2001/2002). In the latter, studies are somewhat shorter than in universities where they last between four and five years. Studies are organised by semesters.

The publication "Hochschulstandort Deutschland 2003" gives some interesting data in the form of graphs or tables that we have made into graphs.

Figure 1 for Germany represents the level of unemployment of people with tertiary qualifications from 1996 to 2002. Unemployment reached 227 000 at the end of 1997 then steadily declined before rising again in recent years. This economic cycle should be compared with Figures 2 and 3 for Germany which show enrolment for and the number of graduates in mathematics and natural sciences plus details for engineers. Enrolment decreases during the employment crisis at a time when more graduates come on to the work market and rises again at the end of the period when the number of graduates is still declining.

As regards the document "Towards a European research area" (COM(2000)6 final), the European Economic and Social Committee[19] made the following remark in paragraph 8.3:

"There should also be discussion about how unfavourable (e.g. for career choice) free-market employment cycles can be adequately offset by government 'anticyclical' programmes so as to protect 'human capital'. One reason for the current lack of new recruits in science and technology is that a few years ago a very large number of young scientists – even those with excellent qualifications – were unemployed. A shortage of new recruits leads not just to a shortage of human capital but also to distortion of the age pyramid."

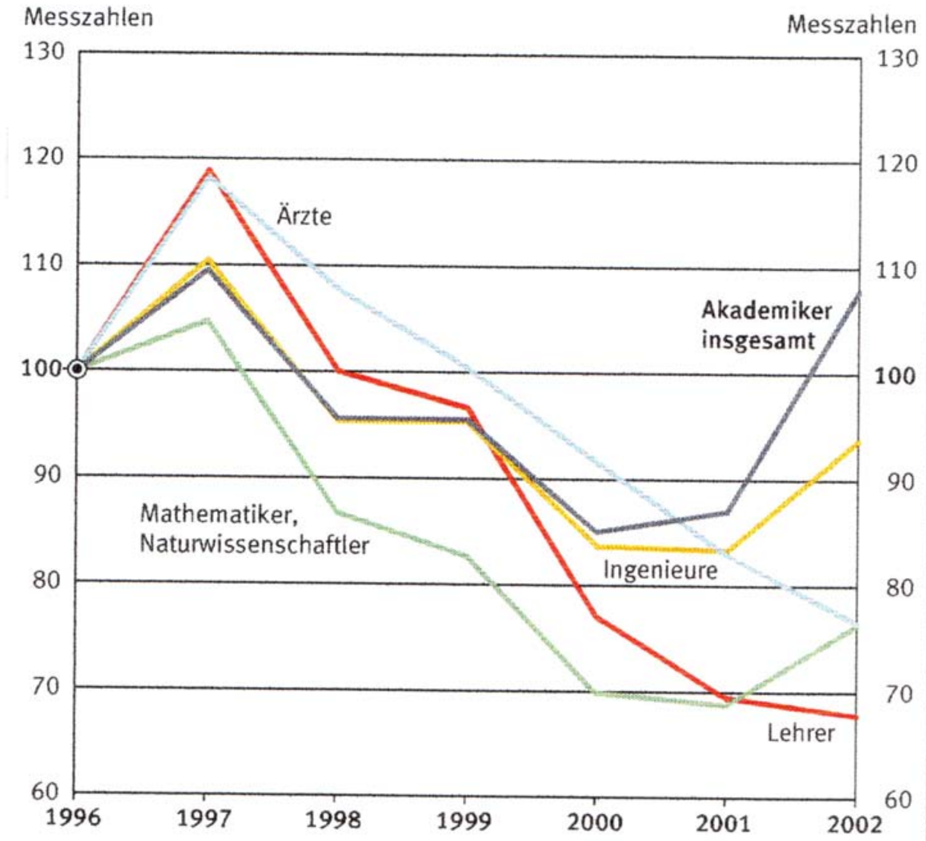
The German statistics illustrate that point perfectly. With reference to the case study of France above it can be noted that the recent downward trend in enrolment corresponds to poor prospects for scientific employment due to restrictions particularly in the public sector which makes up half of the R&D employment in this country. Once again, this is at a time when the number of graduates is high.

The other figures (4 and 5) in this German case study show the disciplinary evolution of enrolment and graduates from 1993 to 2003. The anti-cyclic effect is especially clear for physics and chemistry.

---

[19] European Economic and Social Committee CES, 595/2000 p.15; we would like to thank Dr Wolf for bringing this document to our attention

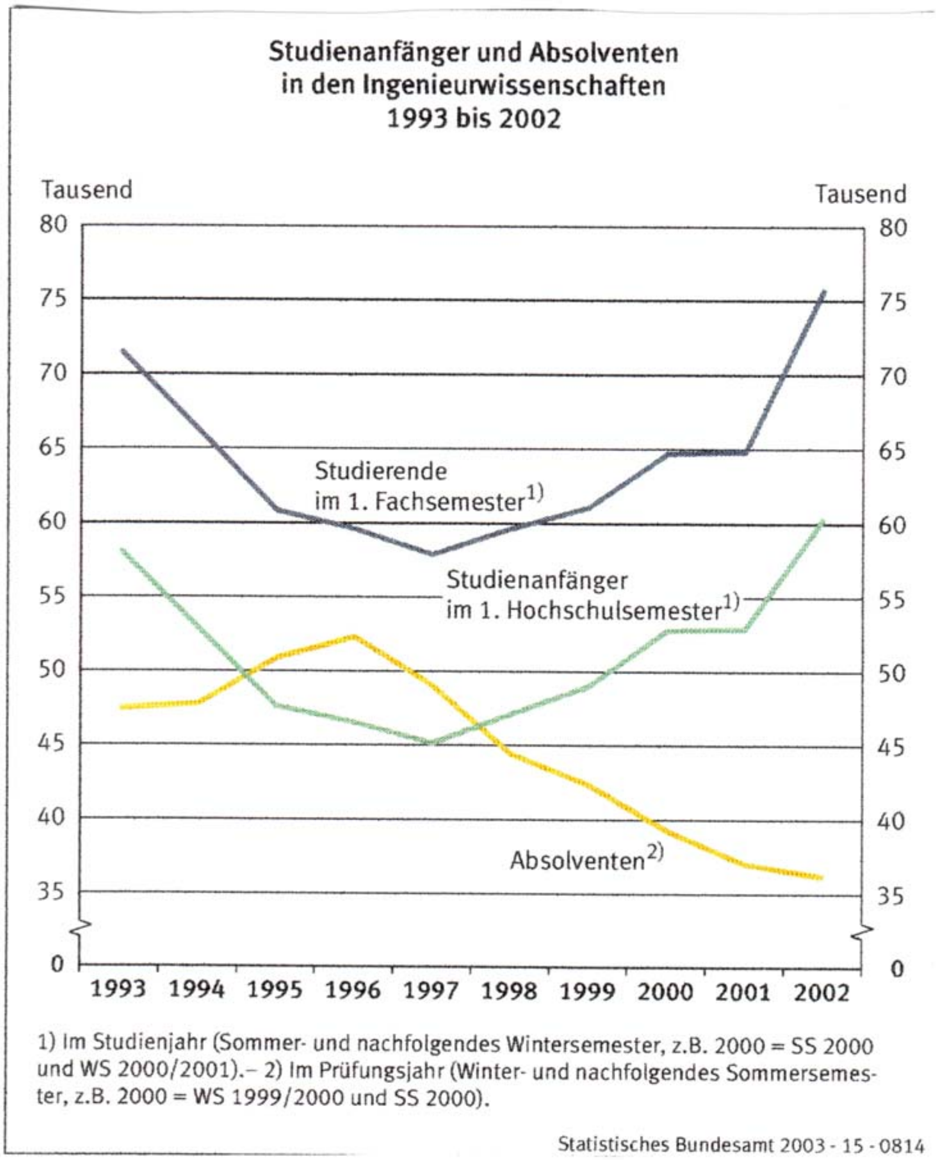
Arbeitslose Akademiker,
darunter Ärzte, Naturwissenschaftler, Ingenieure und Lehrer
1996 bis 2002[1)]
1996 = 100



1) Jeweils Monatsende September.
Quelle: Bundesanstalt für Arbeit: Amtliche Nachrichten der Bundesanstalt für Arbeit (ANBA), Strukturanalyse.

Statistisches Bundesamt 2003 - 15 - 0812

Figure 1. **Germany: Unemployment rate for academics – doctors, natural sciences, engineers and teachers, 1996-2002.**

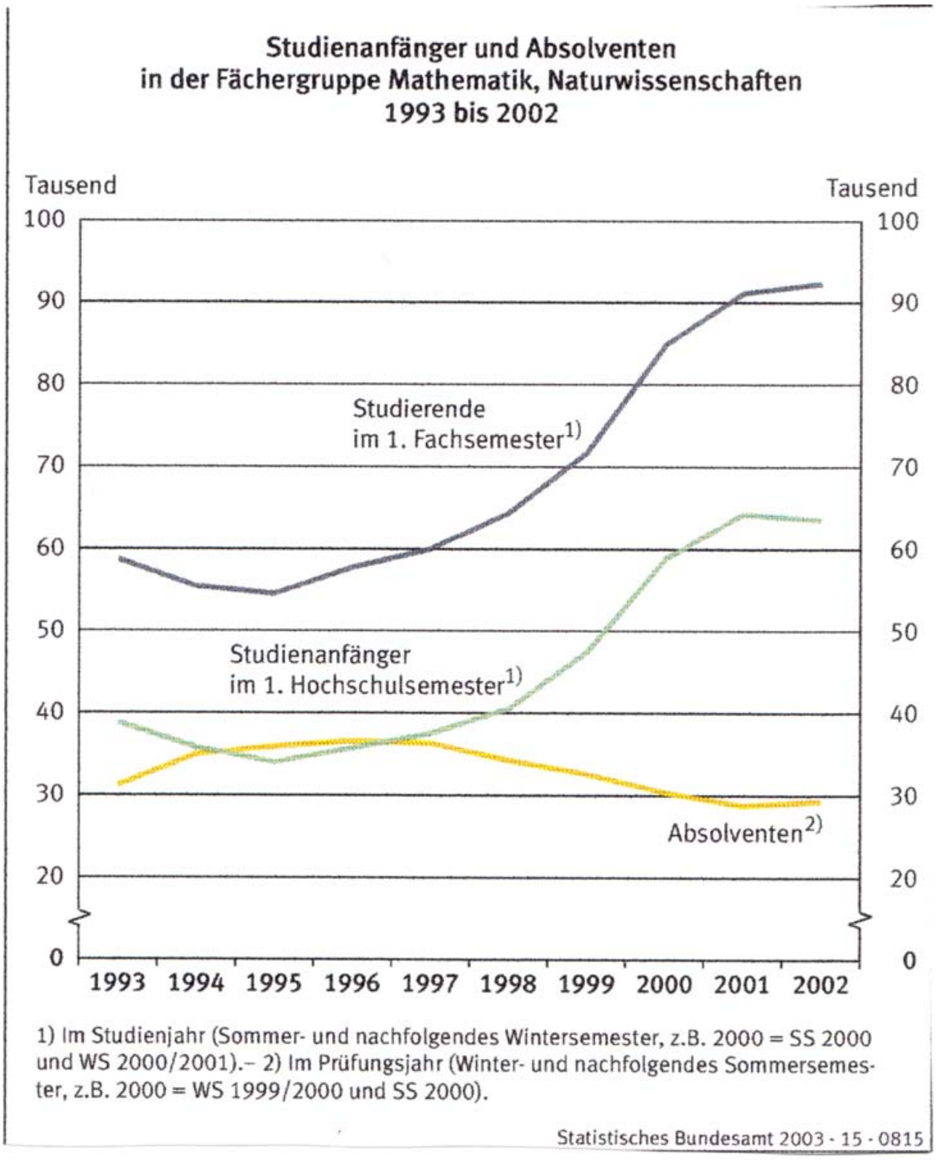


Studienanfänger und Absolventen
in den Ingenieurwissenschaften
1993 bis 2002

1) Im Studienjahr (Sommer- und nachfolgendes Wintersemester, z.B. 2000 = SS 2000 und WS 2000/2001).– 2) Im Prüfungsjahr (Winter- und nachfolgendes Sommersemester, z.B. 2000 = WS 1999/2000 und SS 2000).

Statistisches Bundesamt 2003 - 15 - 0814

Figure 2. **Germany: Enrolment and graduates for engineering.**



1) Im Studienjahr (Sommer- und nachfolgendes Wintersemester, z.B. 2000 = SS 2000 und WS 2000/2001).– 2) Im Prüfungsjahr (Winter- und nachfolgendes Sommersemester, z.B. 2000 = WS 1999/2000 und SS 2000).

Statistisches Bundesamt 2003 - 15 - 0815

Figure 3. Germany: Enrolment and graduates in mathematics and natural sciences.

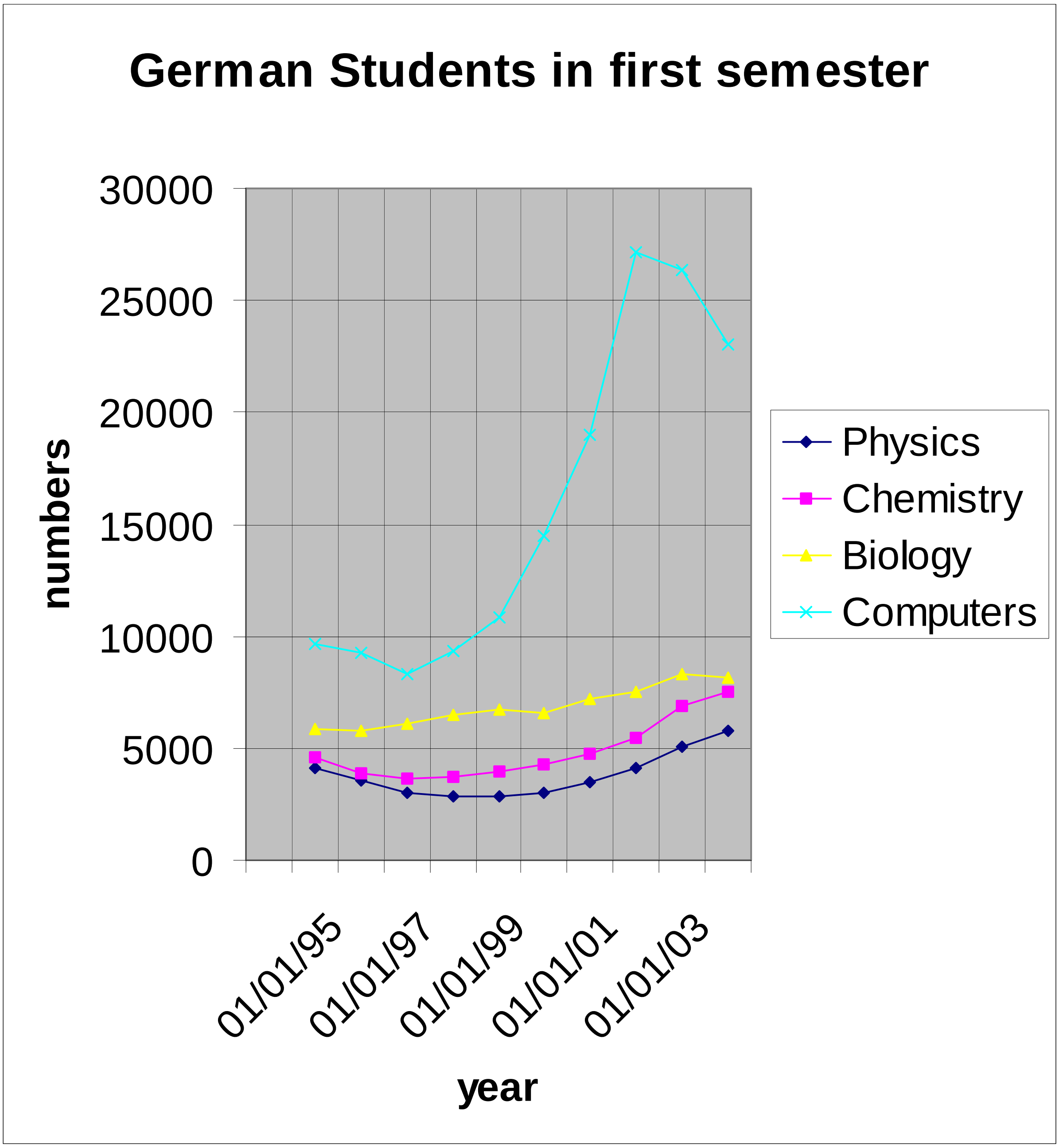


Figure 4. **Germany: Enrolment in disciplinary fields.**

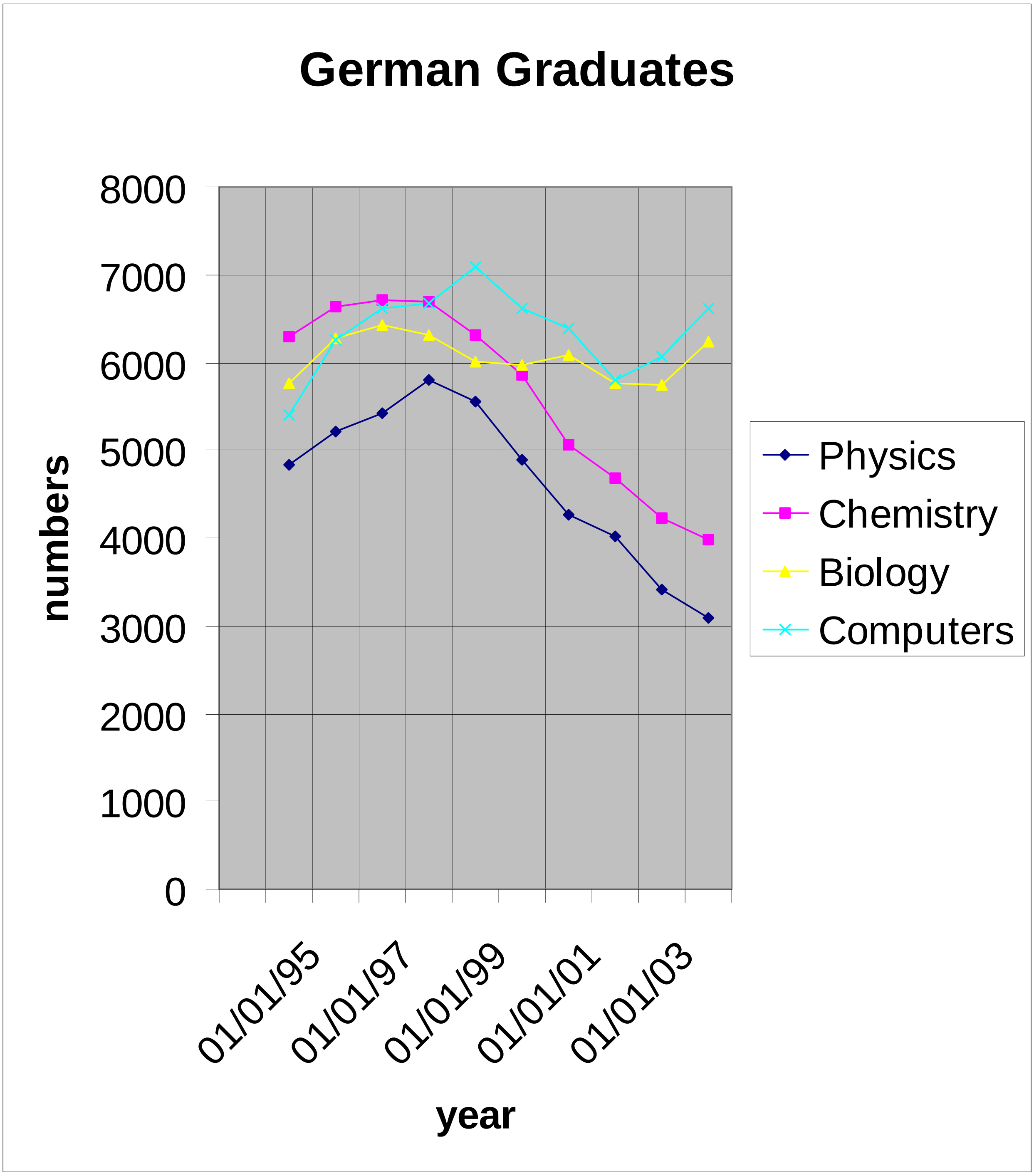
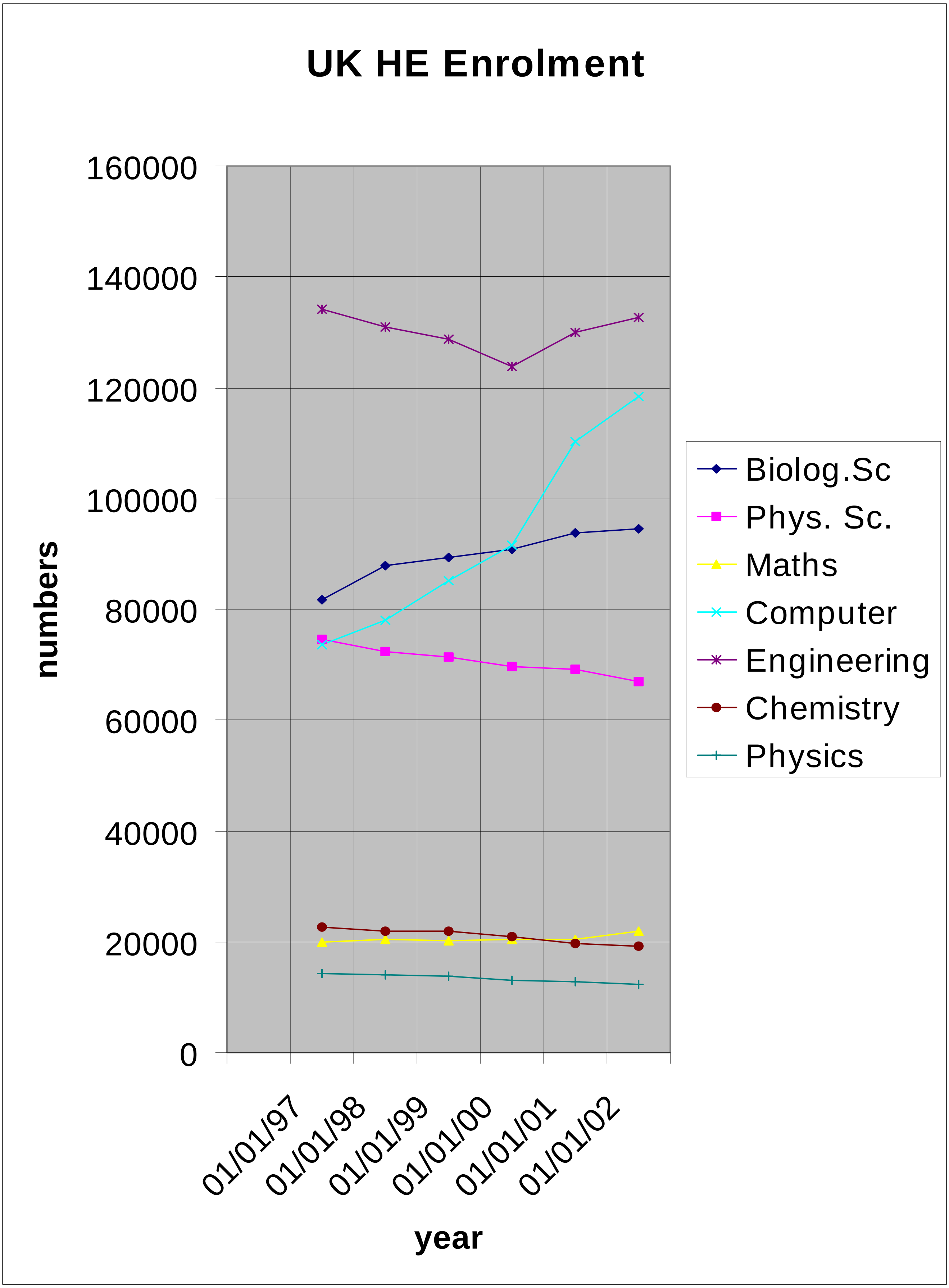


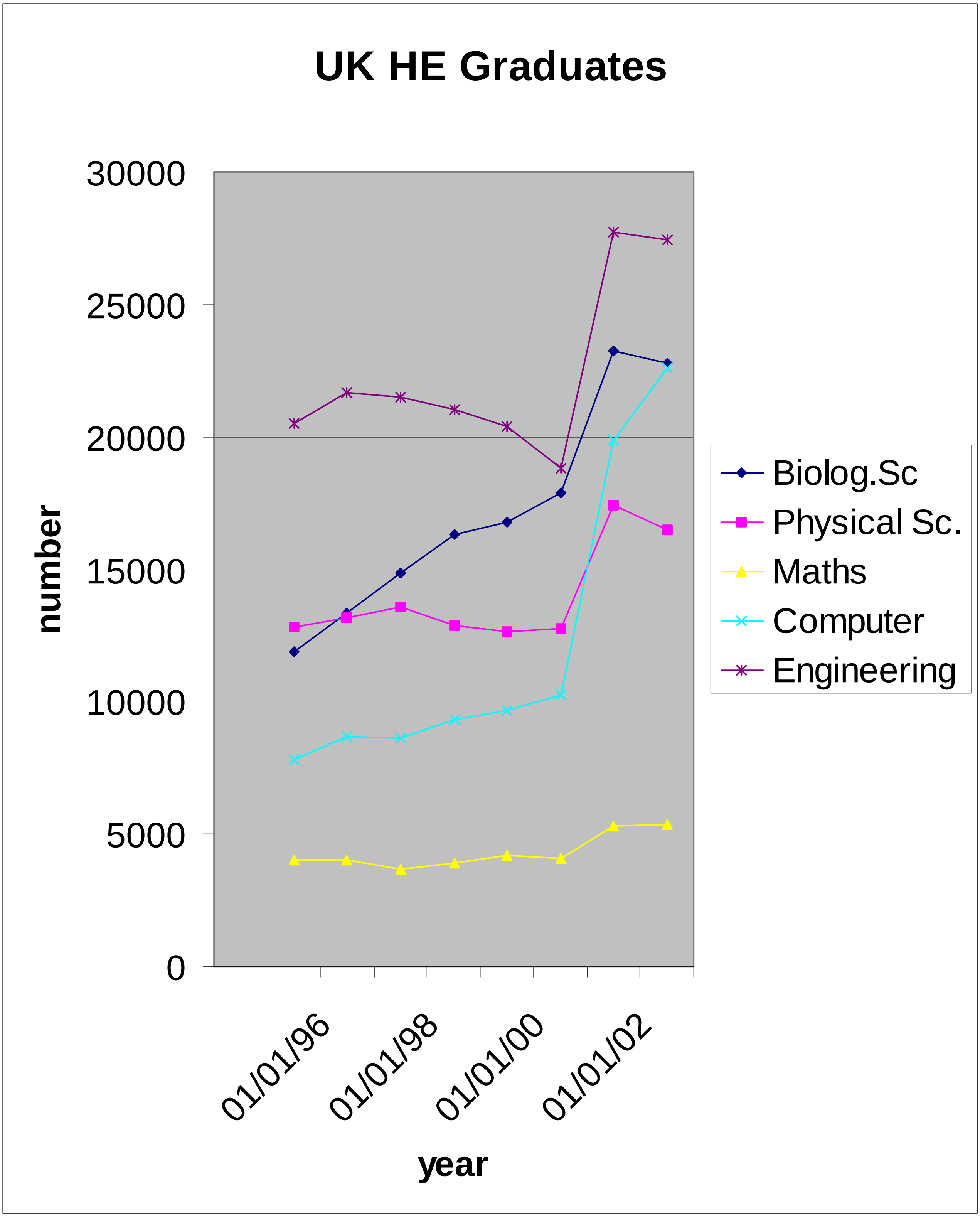
Figure 5. **Germany: Graduates in disciplinary fields.**

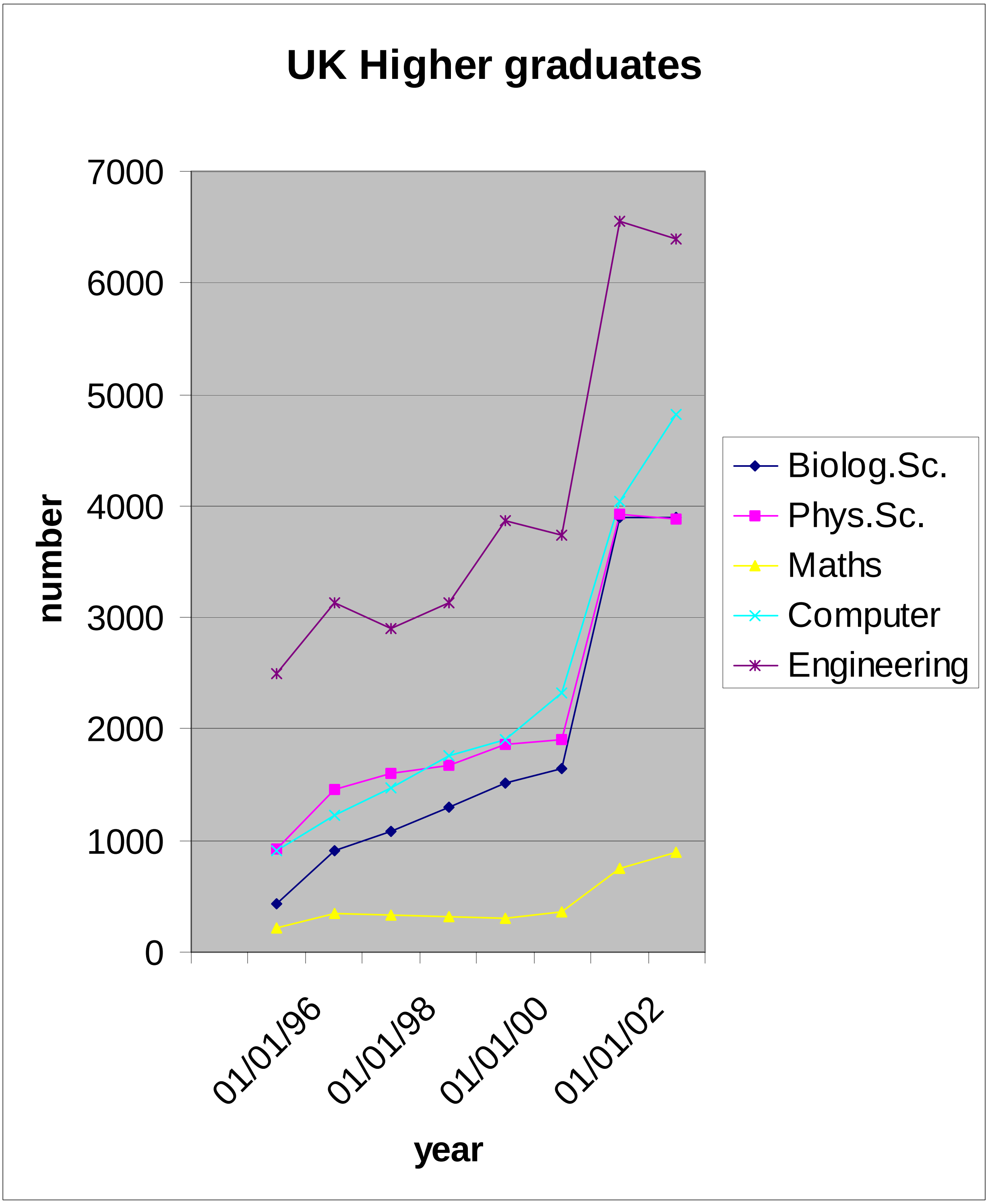
2.5 Case study: UK

We used the data provided by the Higher Education Statistics Agency to review enrolment in scientific subjects in UK universities. These statistics are very detailed and break down into specialities by fields of study. We have made the choice of biological sciences, mathematics and statistics, computer science, engineering and technology, and physical sciences. Within this last category we also collected separately the data for physics and chemistry. Between 1996-1997 and 2001-2002, the student population in UK universities has grown by 18.8% from 1 756 179 to 2 086 179. The number of students registered in the science topics listed above grew 15.7% for life sciences, decreased by 10.2% for physical sciences, jumped by 61% for computer science but was more or less stable for maths and engineering. The increase in university population does not benefit the former hard cores of science and technology. In 1996-1997, physical sciences accounted for 4.2% of students, falling to only 3.2% in 2001-2002. Enrolments in chemistry and physics are steadily declining (Figure 1 for the UK).

As for graduates, we identified two categories: overall graduates by disciplinary fields as above (Figure 2, UK) and what are called ‘higher degrees’ which include doctorates, masters degrees and higher bachelors degrees (Figure 3, UK). There is a sudden increase in the numbers at this level in 2000-2001 which produces a sharp rise in all the curves. That rise can also be seen in OECD data and may be due to a change in accounting, or in the way statistical data are collected. Consequently, the origin of the sharp rise in graduates seen for the UK in recent years should be investigated before speculating on it. The higher education graduate numbers increase quite clearly in life science and computers but are more or less stable or decrease slightly in the other fields. The higher education graduates (PhD, etc.) grow steadily which is opposite to the trend in enrolment in some fields, which has also been noted in other countries.


UK HE Enrolment
numbers
160000
140000
120000
100000
80000
60000
40000
20000
0
01/01/97
01/01/98
01/01/99
01/01/00
01/01/01
01/01/02
year
Biolog.Sc
Phys. Sc.
Maths
Computer
Engineering
Chemistry
Physics


UK HE Graduates
number
30000
25000
20000
15000
10000
5000
0
01/01/96
01/01/98
01/01/00
01/01/02
year
Biolog.Sc
Physical Sc.
Maths
Computer
Engineering


UK Higher graduates
number
7000
6000
5000
4000
3000
2000
1000
0
01/01/96
01/01/98
01/01/00
01/01/02
year
Biolog.Sc.
Phys.Sc.
Maths
Computer
Engineering

2.6 Comparison of the numbers of tertiary graduates

The EU-25 produces more *tertiary* graduates in S&E than the USA and Japan (306 000 more than the US and 440 000 more than Japan). The growth in the number of S&E graduates between 1998 and 2001 was 18% for the EU-25 compared with 6% for the US and a decrease of 1% in Japan[20]. There are twice as many S&E PhDs in Europe than in the US. 2.5% of the population in Sweden and Switzerland have a doctoral degree, 2% in Germany and Finland – the mean value in the EU-15 is 1%[21]. In 2000, there were 2.14 million graduates (all fields) in Europe as against 2.07 million in the US and 1.1 million in Japan – 26% were in S&E, 52% were in social sciences, humanities and education, and 16% in health and food sciences. There are more graduates in Europe in engineering than in science, and the overall proportion of graduates in S&E is less in Japan (21%, and they have far fewer science graduates) and in the US (17%, with engineering and science equal). The largest flow of graduates in S&E is observed for Ireland (35%), Sweden (31%), and France, Austria and Finland (all 30%). Germany, Spain, the UK and Italy meet the EU average (26%)[22]. Meanwhile, only 21% of the population aged 25 to 64 in the EU have achieved university level studies as against 37% in the US and 34% in Japan. In Southern and Eastern Europe the proportion may be lower than 15%[23].

Employment of graduates (all fields) has been rising in recent years (1998-2001) at a rate of 2 to 6% a year, with the fastest rates observed in Ireland (14.5%) and Spain (10.2%); whereas employment growth rates were low in Germany (0.7%) (see the German case study) and negative in the Netherlands (-0.9%).

The period 1993-2000 has seen increases in the number of graduates in mathematics, science and technology throughout most of the EU (Table 1, Figures 18 and 19). It is important to note that these changes should be offset against much larger increases in the total number of graduates in many of the countries. In 1990, European universities accepted 9 million students; in 2000, this number had risen to 12.5 million. Hence, the proportion of students entering S&E programmes would appear to be falling (see, for example, the UK case study above).

Figure 20 shows growth rates in the number of S&E graduates for 1994 to 1996 and for 1998 to 2000. In the same figure, the total number of researchers in 1999 is also shown in parentheses beside the name of each region. It is interesting to note that, while the growth rate for the EU-15 for researchers during 1994-1996 was more than twice that of the US (2.00% and 0.93%, respectively), in 1998-2000 the EU-15 was lagging behind the US (2.66% and 2.95%, respectively).

---

[20] European Commission, Community Research, Key Figures 2003-2004, p. 50

[21] OECD Science and Technology Scoreboard 2003, p. 52

[22] European Commission Third European Report on Science and Technology Indicators 2003, p. 186

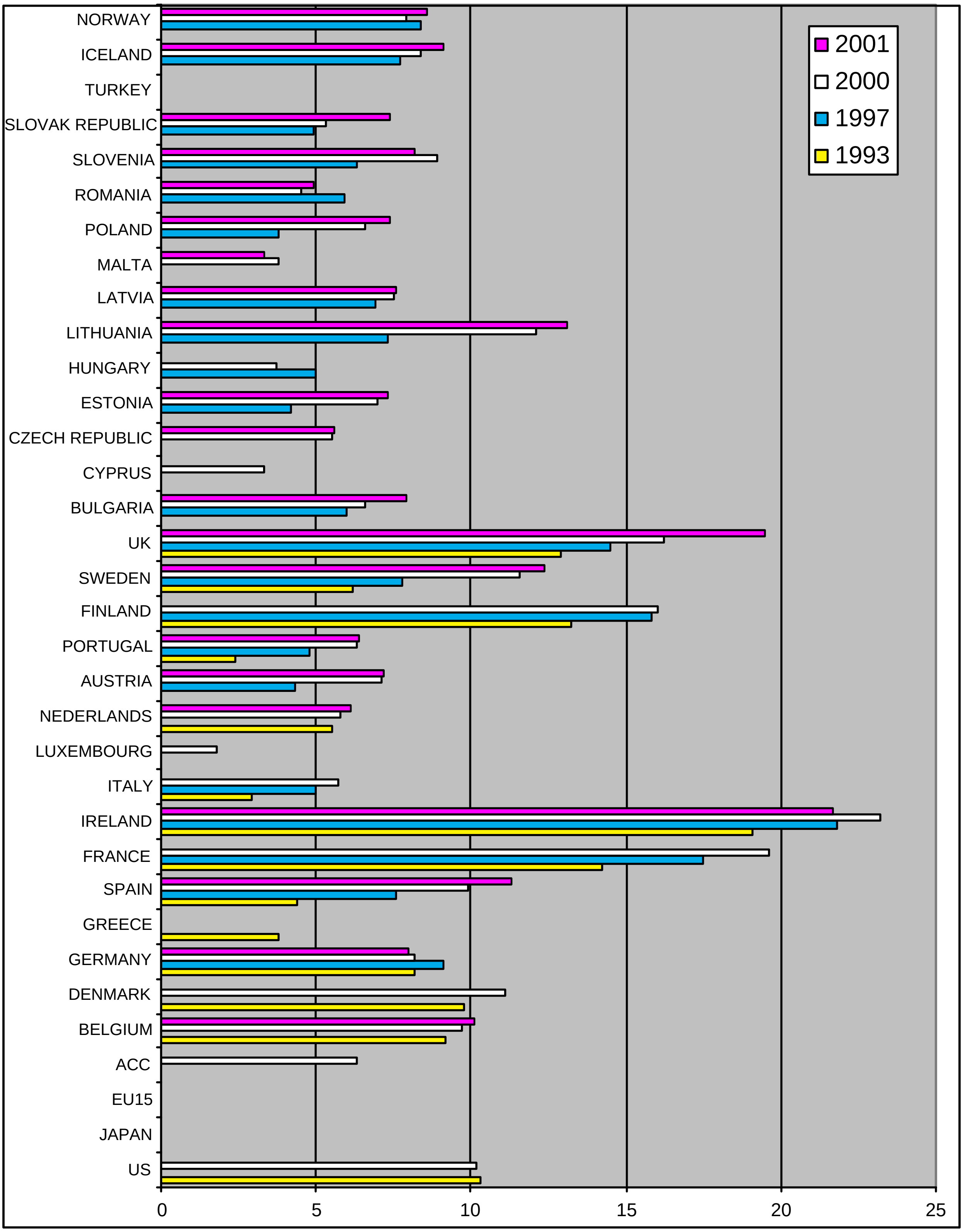
[23] Note 18, p32

Table 1. Total tertiary graduates in science and technology per 1 000 of population aged 20-29.

	1993	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**
US	10.3	10.9	11.2	11.5		9.6	9.7	10.2	
JAPAN			12.7	12.5					
EU-15									
ACC								6.3	
BELGIUM	9.2							9.7	10.1
DENMARK	9.8		9.6	9.4		8.1	8.2	11.1	
GERMANY	8.2	8.9	9.3	9.3	9.1	8.8	8.6	8.2	8
GREECE	3.8								
SPAIN	4.4	5.1	5.8	6.6	7.6	8	9.5	9.9	11.3
FRANCE	14.2				17.5	18.5	19	19.6	
IRELAND	19.1	21	21.4	21.9	21.8	22.4		23.2	21.7
ITALY	2.9	2.8	2.9	4.1	5	5.1	5.4	5.7	
LUXEMBOURG						1.4		1.8	
NEDERLANDS	5.5	5.4	5.6	6.6		6	5.8	5.8	6.1
AUSTRIA		3.2	3.3	3.6	4.3	7.7	6.8	7.1	7.2
PORTUGAL	2.4	3.8	3.9	4.1	4.8			6.3	6.4
FINLAND	13.2	13	13	13.1	15.8	15.9	17.8	16	
SWEDEN	6.2	6.3	7.3	7.4	7.8	7.9	9.7	11.6	12.4
UK	12.9	13.7	13.5	14.3	14.5	15.2	15.6	16.2	19.5
BULGARIA					6	5.5	6.5	6.6	7.9
CYPRUS						3.9	4	3.3	
CZECH REPUBLIC						4.6	4	5.5	5.6
ESTONIA					4.2	2.9	5.7	7	7.3
HUNGARY					5	5.1	4.5	3.7	
LITHUANIA					7.3	8.6	10.8	12.1	13.1
LATVIA					6.9	5.9	6.3	7.5	7.6
MALTA							1.3	3.8	3.3
POLAND					3.8	4.3	5.5	6.6	7.4
ROMANIA					5.9	4.2	4.1	4.5	4.9
SLOVENIA					6.3	8	8.4	8.9	8.2
SLOVAK REPUBLIC					4.9	4.3	5.1	5.3	7.4
ICELAND				7.9	7.7	7	6.3	8.4	9.1
NORWAY			8.5	9.1	8.4	7.5	7.2	7.9	8.6

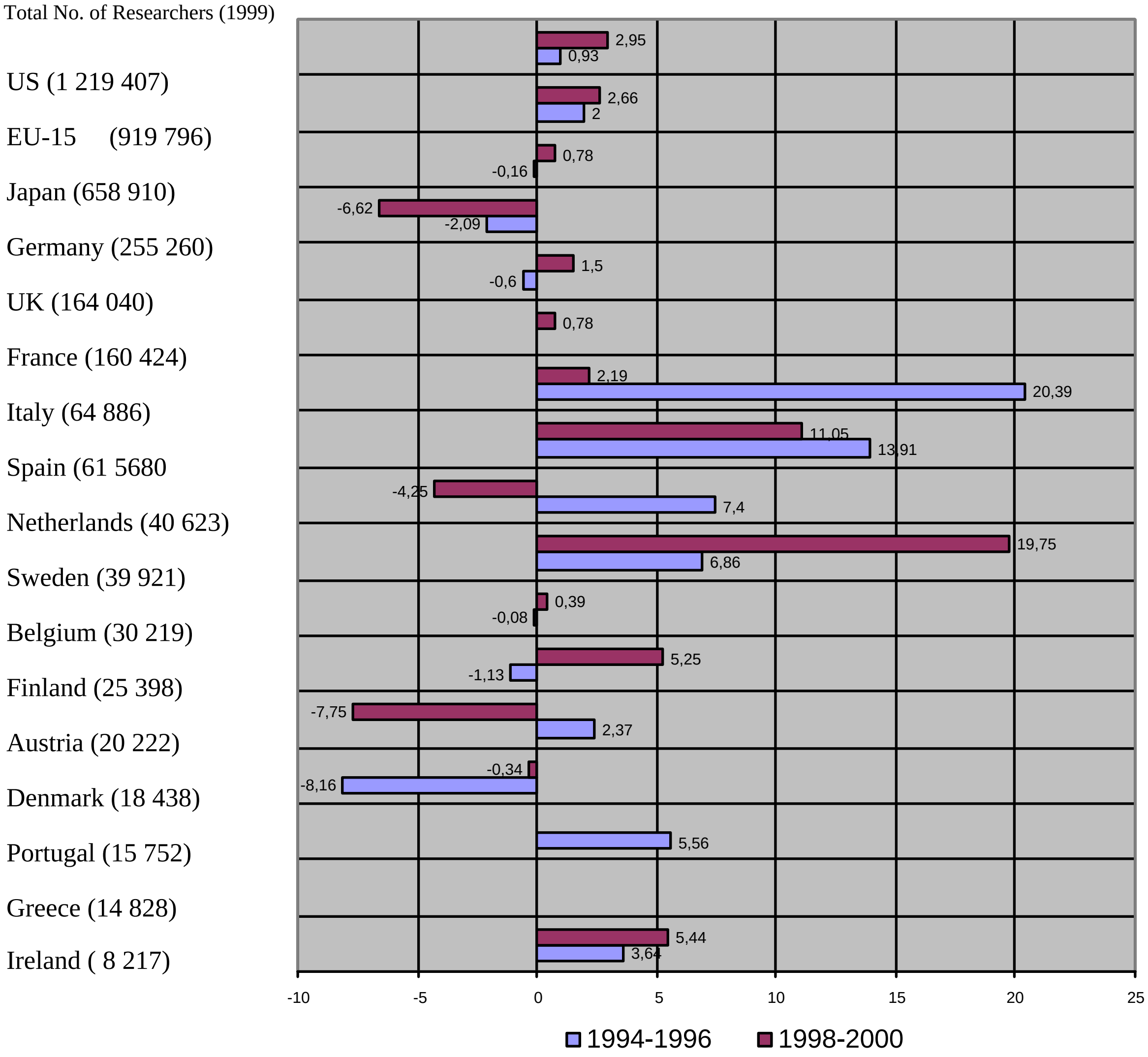
Data compiled from Eurostat Education Statistics, 2003

Figure 18. Evolution of total tertiary graduates in science and technology per 1 000 of population aged 20-29, 1993-2001.



Data compiled from Eurostat Education Statistics, 2003

Figure 19. Graduates in S&E: average annual growth rates in % (1994-1996 and 1998-2000)



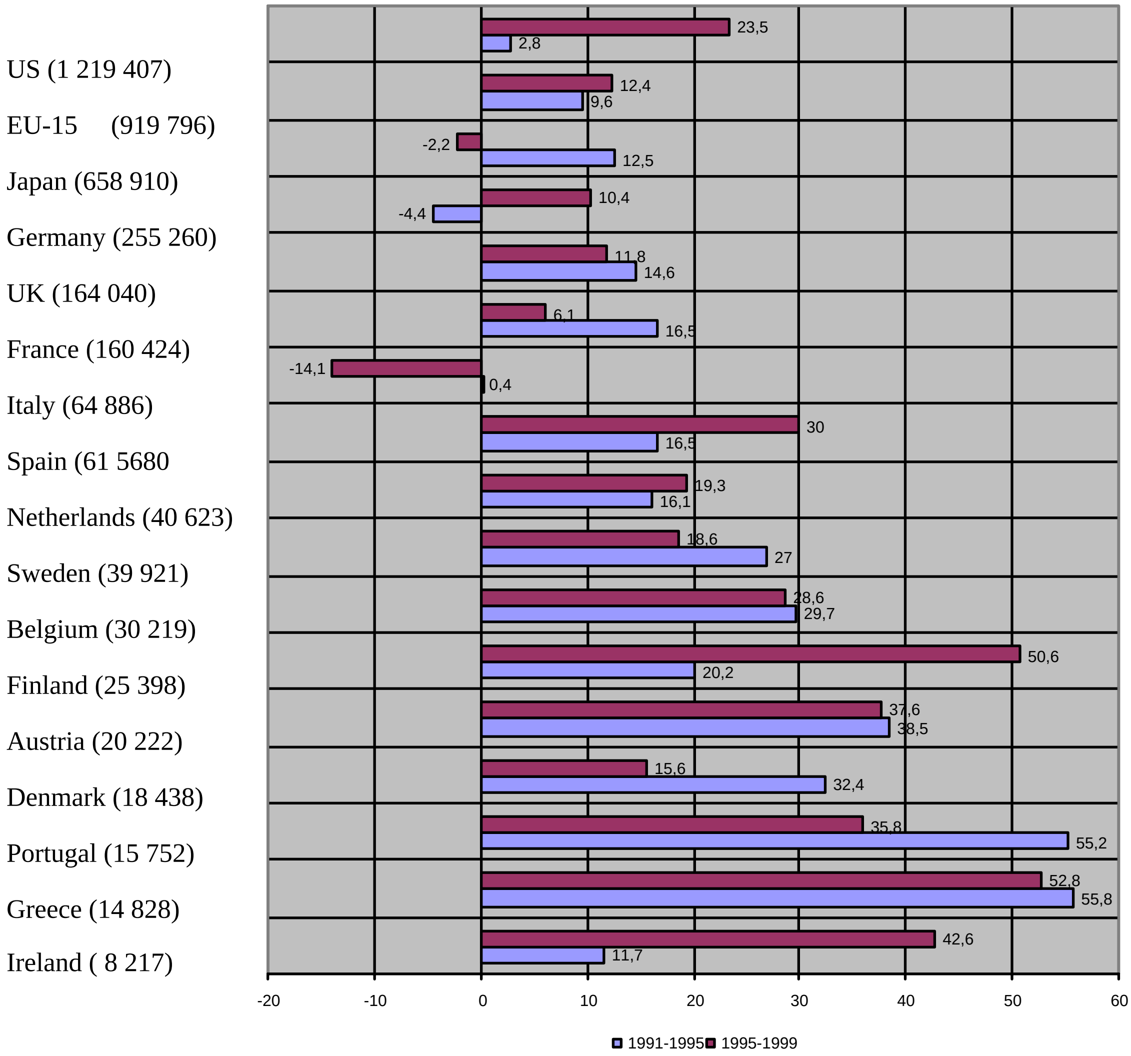
Source: DG Research: Third European Report on S&T Indicators, 2003

Data Eurostat

Note: 1998-1999: No data for EL, and PT which are not included in the EU average. Data for DK, FR, IT and FIN refer to 1998-1999

1995-1996: No data for EL, FR, which are not included in the EU average. No time series for BE because of different populations covered (Flemish Community and total Belgium). BE is not included in the EU average

Figure 20. **Total number of researchers in 1999 and total growth in % (1991-1999).**



Source: DG Research
Data OECD, MSTI database
Note: Numbers of researchers are given in field-time equivalent (FTE). No data for LU, which is not included in EU average. 1999: data for IE, IT, UK, are estimated; 1991: data for NL and PT are estimated. Estimates: DG Research, Third European Report on S&T Indicators, 2003

2.7 Demographic trends

Demographic trends are important parameters for the future of the nations in Europe. They are also very different from nation to nation in Europe. According to Eurostat[24], the European population (EU-15) may start to decline around 2020, especially in Germany, Italy and Spain.

The 25-64 age group presently engaged in S&T has been projected (from demography alone) to increase at a low rate of 1.5% up to 2010 with large national differences (Ireland +17.5%, Portugal, Spain and France around 5 to 7%, but Germany -4.4%)[25]. The 25-34 age group who will fill the positions opened up by retirement in the higher age group will shrink by an overall European rate of 16% especially in Italy (-25%), Germany (-22%), Austria (-20%), Netherlands (-20%) and Denmark (-19%). But in this age group the proportion of graduates in S&T is rather low and may be improved.

As recommended by the 2000 European Council in Lisbon, improving secondary and upper secondary education may be a way to fight the potential S&T shortage due to demography. There are large reserves there as, in 2000, 66% of the EU-15 population in the 25-59 age group has at least an upper secondary education. But the proportion is about 80% in countries like Germany, the UK and Denmark, and much lower in Italy (48%), Spain (40%) and Portugal (22%). Italy and Spain experienced vigorous growth in the period 1995-1997, so there is a considerable potential for improvement. The same is true for tertiary education as, on average, only 22% of the population in Europe has completed a tertiary education (remember that this is much less than in the US or Japan, see above). Finland, Sweden, the UK and Belgium are near or above 30%, but Austria only reaches 15% while Portugal and Italy are at 10%. The proportion of higher educated in the younger age group (15-34) is a critical parameter for the future. Ireland and Portugal have a ratio of about 50% whereas Austria and Sweden are at 22% and Germany and Finland at 25%. The population balance between the younger and the older group and the degree of achievement in education will decide the outcome. But if one wants to go far beyond the simple replacement of the workforce in S&T in Europe alongside unfavourable demographic evolution, drastic progress has to be made not only in providing convincing reasons for more young people to choose S&T as a career but also in attaining higher levels of achievement in education throughout the whole EU.

---

[24] Eurostat: Demographic Statistics 2002, pp. 125-126

[25] The data presented here are taken from the Third European Report on Science and Technology Indicators 2003, pp. 192-197

2.8 Perspectives

The recent Commission Communication *'Investing in research: an action plan for Europe'*[26] stresses that *"More and more adequately skilled researchers will be needed in Europe in order to fulfil the targeted increase of investment in research by 2010. Increased investment in research will raise the demand for researchers: about 1.2 million additional research personnel, including 700 000 additional researchers, are deemed necessary to attain the objective*[27]*, on top of the expected replacement of the ageing workforce in research."*

In 2001[28], some 1.8 million full-time equivalent (FTE) R&D personnel were employed in Community R&D, of whom fewer than 1 million are considered as researchers[29]. The last available figures show a slight increase (2%) in the total number of researchers in the EU-15 between 2000 and 2001. These developments are broadly in line with those related to the volume of R&D expenditure.

Generally speaking, there is a risk that the supply of human resources in R&D and of teachers to prepare these resources may become inadequate for future needs, at least to achieve the 3% objective, as was shown by the first results of the benchmarking exercise for national RTD policies. Moreover, there is a gap between seemingly favourable prospects, as established by recent macroeconomic analysis (job opportunities for thousands of researchers) and less favourable anticipations, as most of the research organisations experience slow increases or even decreases in private and public investments and less commitment to sustainable positions for researchers.

In order to obtain consolidated career prospects for researchers, making it possible to attain the 3% objective, it is therefore of the utmost importance to reduce this apparent divergence between global needs and microeconomic behaviour.

Whilst recognising that teaching, learning and R&D comprise the potential wellspring of economic growth in the knowledge-based society, this will only be achieved in reality if demand conditions for successful innovation, investment and diffusion are greatly enhanced in the EU compared to that enjoyed by our major international competitors.

Achieving the challenging objectives set at Lisbon and Barcelona must involve a dramatic increase of capacity in the education system, and care must be taken that this increase of quantity is not achieved at the cost of lowering quality standards.

---

[26] R&D Expenditure and Personnel in Europe: 1999-2001, Statistics in Focus, Science and Technology Theme 9 - 3/2003, EUROSTAT, European Communities, 2003

[27] In head count: these are orders of magnitude, the precise results depending on the hypotheses retained. There were about 1.6 million researchers in Member States and acceding countries in 2000

[28] Figures vary from 40 to 75% according to different EU-15 Member States and to industry or academic research activity

[29] Moreover, many small SMEs are involved above all in research into process and/or product innovation

The success of efforts to build sufficient capacity to satisfy the 2010 objectives will also be affected by perceptions of young students regarding career prospects and employability in the research sector. Should they fear that the demand for such qualifications will not be forthcoming from research institutes and innovative enterprises, then they may not opt for such studies or, if they do, may emigrate on graduation.

2.9 The science learning pipeline

Most people do not follow science-related careers. When do they decide that science is not a likely career for them? Studies examining persistence in science through the school and university years reveal many points at which students "leak out" of the science education pipeline[30].

Table 2 is informative in a number of ways. The ages chosen are reflective of the structure of educational systems; this guides the choice of landmark ages at which measurement of student interest are commonly made. It is important to note that these are rough estimates. Strong differences exist when such data are analysed by ethnicity, gender, socio-economic status and culture. However, the numbers reflect when attitudes are shaped and how school and university might influence such attitude shaping at different stages. Many people lose any personal interest in science by the age of 12. Between the ages of 12 and 16, many studies report strong negative changes in attitudes toward school science[31]. Thus, both early commitment and preparation for SET careers appear to be critical.

Table 2. Estimates of percentages of student who no longer consider a career in science to be a personal prospect at different stages of the educational system.

Age	Percentage stating research in MST is not a career option	Decrease in interest as compared to input at that level
9	20%	20%
12	50%	37.5%
16	75%	50%
18	90%	60%
22	95%	50%
26	98%	60%

Up to the age of 18, the percentage of those considering careers in science and research-related careers are indistinguishable at this level of accuracy. Table 2 is a compilation from numerous studies on student interest in and attitudes towards science.

Fortifying school mathematics and science preparation while introducing young people to the intrinsic interest and relevance of SET fields above and beyond the drudgery which typifies

---

[30] The concept of educational pipeline has been used for decades; Astin is responsible for popularising the term in educational research; Hilton and Lee considered "leaks in" or "leaks out" of the educational pipeline

[31] Woolnough, B. E. (1996), "Changing pupils' attitudes to careers in science", *Physics Education,* 31, pp. 301-308

their perception would have a greater pay-off than subsequent efforts to entice high school students and undergraduates into SET fields and research careers. Most evidence currently reveals that more students move into science earlier rather than later, when curriculum options are still available and mobility is not discouraged either by stringent institutional curriculum requirements or parents and peers. At later stages in the educational pipeline, science attracts few newcomers but mainly battles to hold its adherents.

Students leak out of the pipeline that leads to a scientific career at any of the six age markers. Important leakage occurs at every transition: from middle to high school, from high school to university, and from a first degree to graduate school. Students who lose interest in pursuing SET studies and potential careers at a specific educational time point may do so either because they decide that another field interests them more than science or because they decide to opt out of the educational requirements of a scientific career. The second largest loss of people who choose research-related careers occurs between first degree and graduate school. For many students (in science as in other fields of study) the first degree is an appropriate point for entering the labour market. However, many studies reveal that substantial numbers of students capable of graduate work choose not to make the transition.

Studies exploring the reasons students choose or reject study and careers in science reveal that those who respond positively to science, largely through their school experience but increasingly with age through science as a mature enterprise, find it interesting, enjoy doing science, and derive satisfaction from discovering new things. Those who respond negatively speak of science as being too hard, boring and not of interest to them. It is clear that many students, increasingly with age and school year, find their own science is hard and unimaginative and perceive careers in science as demanding similar hard work in an uninteresting and irrelevant context.

At the age of 13, a similar proportion of girls and boys seem to be considering careers in science. As the students get older, this gender balance is not maintained. Around the ages of 15 to 17, the proportion of girls still considering careers in science drops steeply as the reality of such possibilities and the unattractiveness of science to them personally becomes more evident.

Many students who do see careers in science as being useful do so because they can think of attractive applications in real life. A few see such careers as solving the world’s problems: more say that they would be a medium for helping people. In other cases, specific areas are reasons for attracting students to science: the possibility of working with animals is more of a motivating factor for girls, while working with cars motivates more boys. However, such preferences are not exclusive.

Perhaps the most important message coming from studies investigating the reasons behind attitudinal patterns is that every student is an individual with different abilities, different history and home background, and different aspirations. It is not just the teaching of science that can differ and can, to some extent, be controlled, it is the students themselves who differ and their reaction to the same stimulus cannot be controlled. Different students in the same class receiving the same lessons will speak very differently about their experiences in science and will have very different attitudes towards it. For this reason, it is unlikely that undifferentiated approaches will have an impact on school science, and the complexity of the situation is such that differentiation needs to take place at least with respect to different thematic areas and to gender.

2.10 Conclusions

At a time of mass access to universities, the interests of students are not fully fixed at the beginning of their university studies and the choice of doing scientific studies may depend on secondary education, on personal interests and tastes, on chance, but also on feelings and impressions about what the work market will be. When they grow older, they make a more pronounced effort to choose a career by entering defined tertiary studies. The interest in science is declining in the first years at university, as recognised by many observers, but the number of science *graduates* at the PhD level diminishes only a little and, when combined with the growing number of overall tertiary science and engineering graduates, this translates as an increase in potential S&T workforce candidates. However, there are large differences between European countries with well-marked decreases in the number of students, especially for the physical sciences, in countries such as Germany. The flow of students at university entrance seems to follow (see the German case data) the rise and fall of unemployment for highly skilled R&D workers. Because of the lapse in time of five to six years necessary for graduate education, the market may turn to another perspective and, consequently, the economical need for graduates may follow an anti-cyclic course with more graduates coming to the market at a time when employment is low (as in Germany around 1997). To counter act this tendency, it will be necessary to take appropriate measures so as not to waste human capital.

As the number of students in Europe is quite high, it may be possible for the whole of Europe to catch up with the much larger percentage of R&D workers per 1 000 workforce of the US and Japan or northern parts of Europe. For that to happen, it is necessary to attract more youngsters to the science and engineering area by acting on the undecided cohorts who enter universities by providing them with attractive science courses in the first years. The fact that the first year in university is considered in some countries as a selection point associated with tough teaching may be a cause for *désaffection*. It may be relatively easy to correct this situation by making lectures and practical classes more attractive (and to spend an amount of money per student at the same level as the US). To get a much larger workforce in S&T than the present one, with its perspectives of slow growth, a significant effort has to be made to induce many more students to take science and technology courses. The effort has to be organised on a European scale, especially in the southern and eastern parts of Europe which hold huge reserves of potential talents. It can begin at a very young age in primary schools in order to correct the sometimes bad images of science, especially for girls, that the entertainment industry and mass media diffuse on a large scale.

Of course, the economical perspectives have to be good enough to warrant a rise in European employment in R&D. The problem of better opportunities elsewhere for scientists is very acute, as shown by the large number (400 000) of European scientists now working in the United States[32]. As most employment for scientists is created in the industrial research sector, better conditions for the development of research by the private sector have to be reinforced in Europe if the Lisbon and Barcelona goals are to be met. On the other hand, the level of public funding per researcher in Europe is clearly well below that in the US. It is not surprising, therefore, that the number of European researchers, namely in the public sector, does not translate into the same level of working conditions and, consequently, of results. The conditions and prospects for employment in the public sector (for universities, public research

---

[32] See *Time Magazine*, 19 January 2004

centres or other publicly funded research institutions) should be recognised as critical for the EU strategy. New human resources for S&T will not be attracted at the required level if governments do not translate their own political goals urgently into new research jobs and better career perspectives. This conclusion is even more important in periods of economic slowdown.

3 Demand and supply in the SET labour market

Summary

The Council of Ministers meeting in Lisbon, 2000, agreed to increase the EU expenditure on R&D to 3% of GDP by 2010. The natural consequence of this is that many more people trained as researchers in SET will be required by that date. From the Commission's own figures the extra numbers are in the order of 700 000. This chapter explores where this demand is likely to arise and the concomitant implications for the supply side. It has been shown that the largest increases in R&D spending will have to be met by industry. EU industry spending on R&D lags well behind that of its competitors in the USA and Japan. It has proved to be a recondite task to estimate exactly where and in which sectors of the economy that the demand will be most keenly felt. In any knowledge-based economy it is prudent to expect the demand to be across all industrial sectors. This does not ignore the fact that well-established industries will be drawing heavily on new technologies to make their business more competitive in the global market place. In addition, technology and the acquisition of technology has become global over the past few years, and this has given rise to a new paradigm in R&D. Businesses can no longer go it alone – they have to rely on new players in the technology stakes, whether this means exploiting their supply chain, venture funds, academia or inorganic acquisition via start-up companies. This has lead to the death of the concept of the corporate laboratories and corporately funded R&D. In general, they have now become the integrators of technology, not the primary movers in its discovery. This in itself has lead to a new role for universities where, in partnership with industry, they will become the outer 'radar' for businesses on new technology.

From a supply perspective, it has been argued that on the present trajectory of increasing the numbers entering SET careers, EU ambitions will not be met. There is a need for a step change in recruitment into SET at all levels. Dramatically increasing the number of women entering SET careers would go a long way to helping to solve the problem, whereas reliance on importing suitably qualified workers from outside the EU is not sustainable in the long term, given the global nature of the market and the dynamics at play. It should not be forgotten that the EU itself is a source of such workers for other knowledge-based countries. When this is put alongside the ageing SET population, the growing shortage of teachers and the greying of academic staff, then the situation is serious. Only radical solutions are appropriate and must include the commitment to inject large portions of both national and Commission budgets into solving the problem. It is also apparent that this shortage is not felt across the whole of Europe, although it is argued that this in itself is not a steady state and migration to satisfy demand will surely occur. The need for standards in education and qualifications will be necessary if the ERA is to succeed. The Bologna Accord is a start in this process but it will only be successful if it embraces credit transfers and not time served on academic courses.

3.1 Aiming at a moving target

It is clear from the facts reported in the previous chapter that the situation is serious. A very large effort indeed will be needed, throughout the Community, to increase the overall SET workforce by the required factor of 50% over a period of ten years. In later chapters of this report we will discuss the various fields of action where this effort should be exerted – public opinion, primary and secondary schooling, higher education, research training, employment policies, etc.

But one of the most distinctive features of SET, both as a body of knowledge and as a means for the production and use of that knowledge, is that it never stays still. Ten years into the future, the European Research Area will not just be an enlarged version of what it is today. Its subject areas, technical capabilities, research methodologies, economic opportunities and organisational arrangements will all have changed as radically as they have in previous decades. Take, for example, the emergence of genomics, information technology, multidisciplinary team research, globalised marketing, and multinational corporate R&D. The target is moving as fast as the mechanisms we are installing to aim at it.

Indeed, many of our present procedures for the recruitment and training of professional researchers are based upon out-of-date conceptions of the type of work such people are expected to do, even nowadays. This is not just the typical lag between science at the research frontier and what is being taught at school and college. Nor is it merely a call for the population at large to become more cognisant of future technological trends as these become more evident in their lives and livelihoods. This lag also applies to perceptions of the employment practices and career paths of qualified SET workers in academia, public-sector organisations, and corporate industry.

3.2 The economic context of SET expansion

At the Council Meeting in Lisbon, 2000, the European Union declared its intent to become a knowledge-based economy. As economies become more knowledge-oriented, this will indeed require a greater number of well-qualified SET people. But this expansion must reflect the realities of today’s economies and not be based on an assumption of stereotyped laboratory-based careers or the traditional separation of basic and applied research in academia and industry respectively. It must also recognise the distinction between vocational careers and the more conventional higher education-based careers.

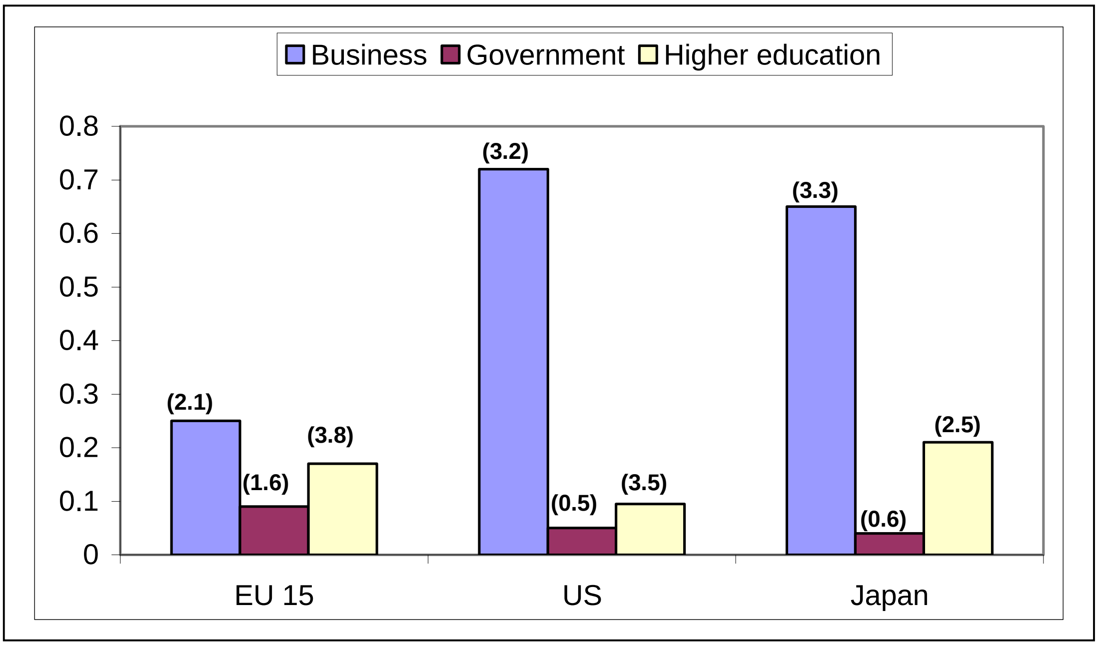
Luc Soete[33] expressed the following in a personal communication:

“There is little discussion and it is widely accepted that both private and public research investment depend to a large extent on the availability of highly qualified research personnel. The greatest part of research expenditures, about 70% of total R&D resources on average, goes to the salaries of research personnel. The available data on SET point to the increasing gap between the US and Europe in privately oriented research, illustrated in Figure 1. Not only is the percentage of SET in total employment in the private sector 2 to 3 times higher in the US and Japan than in Europe, but its growth is also higher in these former countries.

---

[33] Luc Soete (University of Maastricht) “Some personal comments on the human side of Europe’s knowledge gap”, personal communication to the HLG

Figure 1. **SET researchers as a percentage of the total labour force in the EU, the US and Japan (average annual growth rates 1990-98 between brackets).**

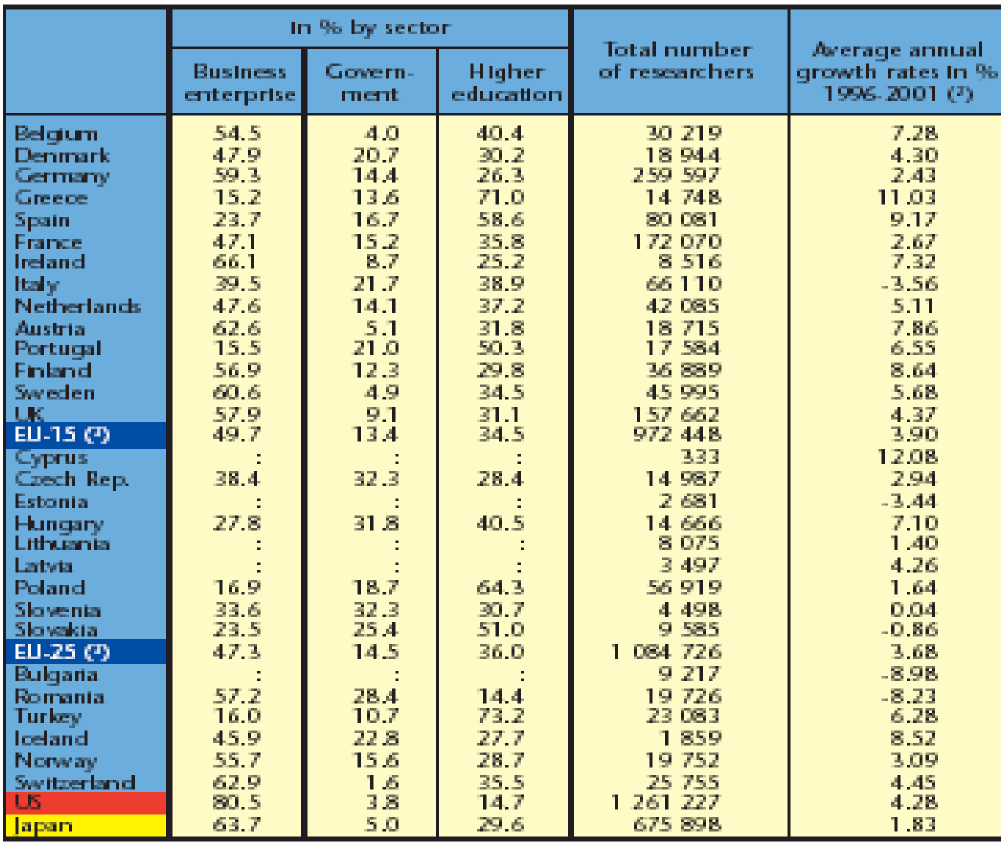


“The availability of sufficiently qualified personnel is absolutely central to any debate on the development of a ‘sustainable’ knowledge economy. Without the availability of additional, highly-qualified research personnel, the aim to double private research investments will merely lead to a tighter labour market and to the ‘poaching’ of personnel from universities and other public research centres or from other European countries, including new member countries or from countries outside the EU that are SET rich. Looking at the current labour costs for R&D personnel, realisation of the Barcelona objective implies a need for an additional supply of researchers between now and 2010 of around 700 000 (Key Figures 2003-2004) full-time equivalents. This should be added to the specific European problem of an ageing population which also affects the knowledge sector: from the growing shortage of teachers in a large number of European countries to the rapid increase in the greying of academic staff in practically all European countries.

As outlined by the EU in its comprehensive Key Figures document, the number of extra trained SET workers required by Europe to meet the 3% target needs to be in the region of 700 000 full-time equivalents. The data is insufficient to distinguish between technical staff, graduates and doctorates. However, taken in totality we can estimate the growth in SET research workers by 2010 if present growth rates are sustained. Using (Table 1) data then close to 400 000 FTE researchers would be employed. Nearly 50% would be in the industrial sector, with 35% in academia and 9% in government. Using data from the enlarged community would see some minor changes to the figures, but not enough to affect the overall outcome. The 2010 requirements therefore far outstrip our present capability to supply.

This is true for the EU zone as a whole, although it should be recognised that for certain EU countries this is not a problem, e.g. Finland and Sweden. It is postulated that within these countries there is a heavy reliance on knowledge-based industries already and the economic culture exists to value and enhance SET careers. (In percentage terms, the increases in SET supply in these countries look impressive, but in absolute numbers they do not greatly affect the overall EU position). Also in the future if there is a heavy demand for such qualified people elsewhere in the EU then migration across the continent could prove a problem for these countries.

Table 1. Researchers (FTE) – total numbers and by sector (%), 2001



	In % by sector			Total number of researchers	Average annual growth rates in % 1996-2001 (2)
	Business enterprise	Govern-ment	Higher education		
Belgium	54.5	4.0	40.4	30 219	7.28
Denmark	47.9	20.7	30.2	18 944	4.30
Germany	59.3	14.4	26.3	259 597	2.43
Greece	15.2	13.6	71.0	14 748	11.03
Spain	23.7	16.7	58.6	80 081	9.17
France	47.1	15.2	35.8	172 070	2.67
Ireland	66.1	8.7	25.2	8 516	7.32
Italy	39.5	21.7	38.9	66 110	-3.56
Netherlands	47.6	14.1	37.2	42 085	5.11
Austria	62.6	5.1	31.8	18 715	7.86
Portugal	15.5	21.0	50.3	17 584	6.55
Finland	56.9	12.3	29.8	36 889	8.64
Sweden	60.6	4.9	34.5	45 995	5.68
UK	57.9	9.1	31.1	157 662	4.37
EU-15 (3)	49.7	13.4	34.5	972 448	3.90
Cyprus	:	:	:	333	12.08
Czech Rep.	38.4	32.3	28.4	14 987	2.94
Estonia	:	:	:	2 681	-3.44
Hungary	27.8	31.8	40.5	14 666	7.10
Lithuania	:	:	:	8 075	1.40
Latvia	:	:	:	3 497	4.26
Poland	16.9	18.7	64.3	56 919	1.64
Slovenia	33.6	32.3	30.7	4 498	0.04
Slovakia	23.5	25.4	51.0	9 585	-0.86
EU-25 (3)	47.3	14.5	36.0	1 084 726	3.68
Bulgaria	:	:	:	9 217	-8.98
Romania	57.2	28.4	14.4	19 726	-8.23
Turkey	16.0	10.7	73.2	23 083	6.28
Iceland	45.9	22.8	27.7	1 859	8.52
Norway	55.7	15.6	28.7	19 752	3.09
Switzerland	62.9	1.6	35.5	25 755	4.45
US	80.5	3.8	14.7	1 261 227	4.28
Japan	63.7	5.0	29.6	675 898	1.83

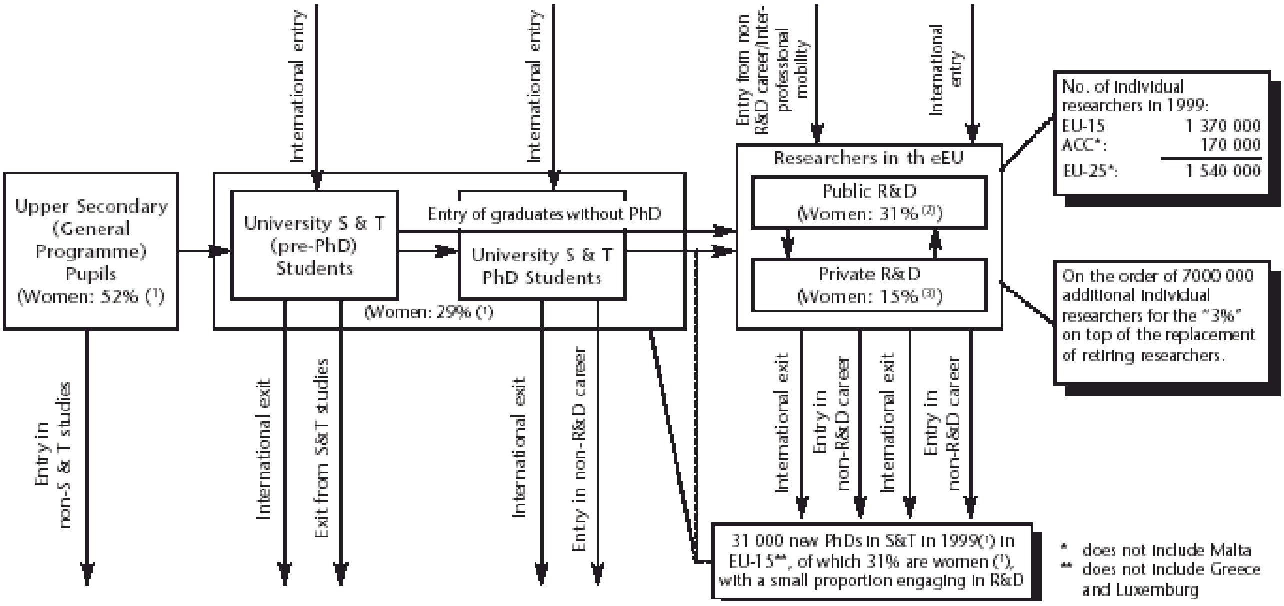
Source: DG Research - Key Figures 2003-2004-01-29

Data: OECE, MSTI 2003/Vol 1, for non-OECD members: Eurostat/Member States

Notes: The sectors do not add up to 100%(1) or latest available year: AT, UK: 1998; BE, DK, EL, US:1999; FR, IE, IT, NL, EU-15, TR, CH: 2000; (2) or nearest available years: AT: 1993-1998; EL: 1995-1999; BE, DK: 1996-1999; FR, IE, IT, NL, EU-15, EU-25, TR, CH: 1996-2000; PT, FI, SE, IS, NO: 1997-2001; CY, EE: 1998-2001; (3) EU-15, EU-25 data are estimated by DG RTD and total numbers do not include LU or MT. EU-25 by sector data exclude LU, CY, EE, LT, LV and MT

The situation is not one of ‘steady state’ – various dynamics are in play. For example, the model assumes that there is no wastage. The EU supply chain of researchers shows in Figure 2 that there are numerous routes for losses. However, these can be offset by entries from other international routes. Although there are data on the numbers of foreign students studying in the EU, there are no corresponding data for those remaining in the EU to work. Similarly, there are data for EU people applying for visas to work/study temporarily in the US. Losses resulting from retirement and the ‘greying’ of academics will add to the problem. The net influx/outflow is difficult to estimate. If we assume it is in balance then the EU still has a large hole to fill in the number of qualified SET workers.

Figure 2. Supply chain of researchers in Europe.



Source: DG Research, European Commission (2003a), Annex, p. 76
(1) Eurostat (2003), Joint Unesco-OECE-Eurostat (UOE) data collection questionnaires. (2) Rees, T. (Ed.), (2002) National Policies on Women and Science in Europe. European Commission (OPOCE Ref KI-NA-20-308-EN-C). 3) Rubsamen-Waigmann, H., et al (2003) Women in Industrial Research: A Wake-Up call for European Industry. STRATA ETAN, European Commission (OPOCE Ref. KI-46-02-759-EN-C).

If the regional variations in SET researchers hold until 2010 then, as well as an imbalance in supply, there will also be an imbalance of academic vs business personnel between northern and southern Europe, roughly. The higher percentage of business SET researchers (~50% of the total) are in northern European countries as against ~20% in southern European countries. In terms of academia, the trends are reversed. The consequence of this could be the market-forced migration of qualified SET researchers across the EU. The standardisation of qualifications then becomes important, as will be discussed later in this chapter. This migration could be further exacerbated by the enlargement of the EU-25, whose Member States tend to mirror those of the southern EU.

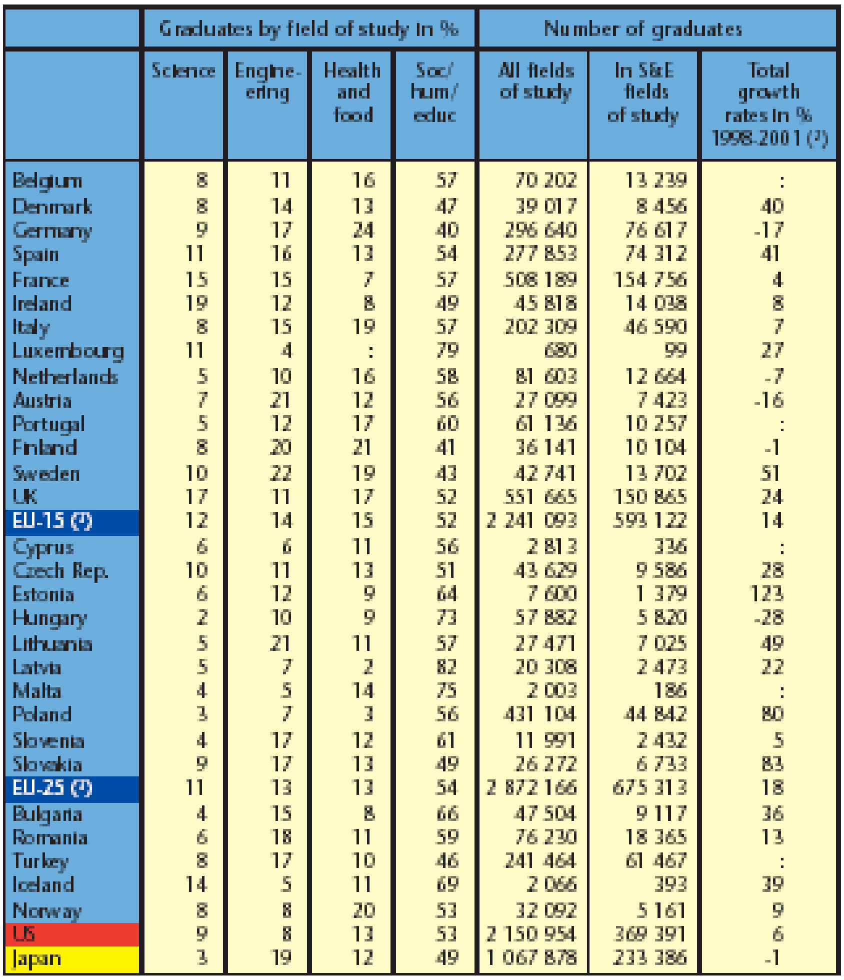
Women in SET

Women are an under-exploited resource for research in the EU. From the Commission's 'Key Figures 2003-04' the share of women in the total number of researchers is shown in nearly all countries to be below 50%, and for the EU as a whole, to be close to 27%. This under-representation of women in research results from different factors such as lower participation in SET-related studies, different career models, and historical and current discriminations. These are important starting points for the implementation of policy measures to encourage the participation of women in research, which would go a long way to filling the HR gap.[34]

---

[34] See also EU's "She Figures" (European Commission/DG Research 2003b)

Table 2. University graduates (ISCED 5 and 6) in 2001.



	Graduates by field of study in %				Number of graduates		
	Science	Engineering	Health and food	Soc/ hum/ educ	All fields of study	In S&E fields of study	Total growth rates in % 1998-2001 (2)
Belgium	8	11	16	57	70 202	13 239	:
Denmark	8	14	13	47	39 017	8 456	40
Germany	9	17	24	40	296 640	76 617	-17
Spain	11	16	13	54	277 853	74 312	41
France	15	15	7	57	508 189	154 756	4
Ireland	19	12	8	49	45 818	14 038	8
Italy	8	15	19	57	202 309	46 590	7
Luxembourg	11	4	:	79	680	99	27
Netherlands	5	10	16	58	81 603	12 664	-7
Austria	7	21	12	56	27 099	7 423	-16
Portugal	5	12	17	60	61 136	10 257	:
Finland	8	20	21	41	36 141	10 104	-1
Sweden	10	22	19	43	42 741	13 702	51
UK	17	11	17	52	551 665	150 865	24
EU-15 (3)	12	14	15	52	2 241 093	593 122	14
Cyprus	6	6	11	56	2 813	336	:
Czech Rep.	10	11	13	51	43 629	9 586	28
Estonia	6	12	9	64	7 600	1 379	123
Hungary	2	10	9	73	57 882	5 820	-28
Lithuania	5	21	11	57	27 471	7 025	49
Latvia	5	7	2	82	20 308	2 473	22
Malta	4	5	14	75	2 003	186	:
Poland	3	7	3	56	431 104	44 842	80
Slovenia	4	17	12	61	11 991	2 432	5
Slovakia	9	17	13	49	26 272	6 733	83
EU-25 (3)	11	13	13	54	2 872 166	675 313	18
Bulgaria	4	15	8	66	47 504	9 117	36
Romania	6	18	11	59	76 230	18 365	13
Turkey	8	17	10	46	241 464	61 467	:
Iceland	14	5	11	69	2 066	393	39
Norway	8	8	20	53	32 092	5 161	9
US	9	8	13	53	2 150 954	369 391	6
Japan	3	19	12	49	1 067 878	233 386	-1

Source: DG Research - Key Figures 2003-2004

Data: OE database, Benchmarking indicators Eurostat/Member States, Notes: The %s in fields of study do not add up to 100% (1) DK, FR, IT, LU, FI, CY, HU: 2000; (2) DK, FR, IT, LU, FI, CY, HU: 1998-2000; (3) EU-15, EU-25 data do not include EL. EU-15 growth rate does not include BE, PT

Although the demand for SET researchers is not in doubt, the absolute numbers are still open to discussion given all the factors mentioned above. The size of the gap is large and definitely finite. In their paper "Targetting R&D", Sheehan & Wyckoff have discussed the funding gap. Other countries, notably Korea, have attained 3% of GDP. The EU, it is estimated, needs to increase R&D spending to nearly 7% per annum if it is to match this achievement.[35] Of course, with a lead-time of ten years in the production process and very large uncertainties in the likely supply and demand, the requisite investments in human resources cannot be planned in any detail. A great deal will have to be left to organisational flexibility and career adaptability in the SET labour market. Tomorrow's researchers cannot expect to settle early into cosy niches for life. But such adjustments will be frustrated unless all the actors take into account the nature of the likely demand and the barriers to meeting it.

---

[35] "Targetting R&D: Economic and Policy Implications of Increasing R&D Spending", J. Sheehan & A. Wyckoff, OECE DSTI/DOC (2003), p. 8

3.3 Matching supply to demand

Today, the gap in research investment and employment is primarily on the demand side: the desired jobs simply do not exist and will not appear in the requisite numbers just because people are being trained for them. This demand-side gap is a consequence of the form that economic growth has taken in Europe. Companies tend to establish themselves and flourish where there is the greatest likelihood of economic success. This happens most easily and productively where there are the least barriers to company formation and growth, and where sustained, profitable markets exist for their products. In a nutshell, Europe has so far failed to create enough successful companies through a sustained high research intensity. Estimating the demand is a recondite task and it is not sensible to assume a bulk figure based on the 3% target.

There are gaps today on the people supply side. These are primarily in the more traditional disciplines (physics, chemistry, engineering, etc.) and exist at all levels of qualification, technical as well as professional. Filling these gaps is important but will not be sufficient to meet the desired employment goals.

Provided economic and social barriers are eliminated, an improved supply of people can indeed stimulate increased demand and economic growth, thereby creating a virtuous circle. The counter view is probably also true: badly handled, this could trigger a further decline in the attractiveness of SET careers.

This suggests, for example, that solutions based primarily on mechanisms available under FP6 can help, but these are not likely to be the only important or effective mechanisms. Solutions that emphasise ‘research push’ are not effective alone. The most important measures will be those which build European economies that are more flexible, more competitive, and more appealing to the types of people and companies they seek to attract.

It is also significant that European companies are becoming increasingly global and will acquire and recruit an international workforce. If Europe is not to become de-skilled, it must also take measures to compete on the educational stage and provide careers which are attractive, both in style and remuneration, to its future generations.

3.4 New industrial models

It is important to recognise, especially within industry, that ‘research careers’ are quite different today from what they were ten years ago, and that these careers will continue to evolve as economies and new business sectors develop. There are changes both in the type of work researchers do and in how and where they are employed. Present-day industrial and academic R&D practices are not an adequate model for planning the future.

Whereas the previous industrial model was built around vertically integrated large companies with large, centrally funded, corporate laboratories, today’s model for bringing R&D to market involves a much more dynamic acquisition of technology requiring the integration of suppliers, academia, start-up companies, investment funds, etc. This does not imply any less sophistication or a reduced knowledge intensity. It is the process that has changed, with consequent implications for the skills people need to be successful and the ways they will work.

As a consequence, the recruitment profile has also changed. There tends to be less of a need within industry for postdoctorates, but a greater need for postgraduate (master's degrees) and technical staff. In-house training and continued professional development have become essential managerial instruments for moulding people to the work. Specifically, people have had to become better integrators of knowledge, able to accommodate different perspectives of innovation wherever it arises.

Consequently, SET workers are required to be more mobile. It is essential for them to be able to move easily among the various jobs that form the basis of their careers. For example, experience gained in an academic setting is valuable in an industrial setting, and also – critically – vice versa.

It is worth noting that the relative success of the US and the relative failure of Japan in the 1990s can be linked to these societies' different ability to bring in advanced skills from outside and use these skills flexibly; but Europe should not just look to these other regions for solutions.

3.5 The changing face of industry across the EU

After their first phase of rapid growth, the new sector industries, e.g. the so-called 'high tech', 'dot coms', have probably stabilised at a more realistic recruitment rate. The demand for new graduates in these sectors is probably balanced today by the decline in high tech company fortunes, so supply and demand are in balance. For these sectors to thrive, a corresponding upturn in their economic fortunes has to happen. However, there is still unfilled demand in certain sectors for SET qualified personnel.

Total and research-based employment in traditional industries is likely to continue to decline slowly. However, in Europe as a whole, the best of these industries are competitive in performance, numbers and R&D investment (and hence R&D employment) with the US, although Europe does fall behind Asia in terms of its R&D investment in these industries. The importance of such industries should not be overlooked. Thus, food and farming industries have become much more knowledge intensive, even though they have been employing fewer and fewer people ever since the industrial revolution. They will still require SET qualified staff and are probably the most likely to experience difficulties in recruiting these people. The measures taken should be capable of supporting the evolution of these traditional sectors as they compete to create added value, and hold market share, against companies based in lower-wage, yet increasingly highly skilled regions of the world.

It seems likely that universities will play a leading role in stimulating the next phase of new sector growth, as small companies form within the concept known as the technopolis – technology incubation. For this to drive R&D investment, job creation and employment, it is important to establish appropriate policies, conditions and attitudes that stimulate success.

All growth will be cyclical and the EU should plan accordingly. Getting the 'phase' of supply and demand right is critical, particularly in new sectors where the stability of future demand is least certain. We find, paradoxically, that companies cannot recruit the right people with the right skills at the very same time as jobs are being lost.

3.6 New roles for universities

As noted, universities are interacting more closely with industry and acting as industry's 'outer radar' on new technology. This does not imply that they can or should replace industry in taking technology through to market. Their primary commitment is still to create knowledge through research, to act as long-term guardians of this knowledge, to transmit it to others through education, and to train new researchers.

Nevertheless, universities are beginning to operate as new 'corporate labs' for European industry, specialising in applied but long-term research of relevance to industry. This is not a role for all universities but it does enhance by an order of magnitude the concept of a European MIT. It is envisaged that major companies will form special relationships with particular universities for a supply of both qualified people and research.

The intermediate stage of testing, experimenting, and creating new options is increasingly becoming the role of the academically close start-up company. The large firms provide the major channels through to market and the 'clout' to make things work. All three parts of the system – knowledge generation, testing and integration – need to work well and smoothly together. This implies careful consideration of the manner in which clusters are built and supported. Within European cultures, it begs the question of who should be responsible for this process?

As providers of long-term, applied research for industry, universities have good reason to form collaborative partnerships with industrial firms. Although it is still unclear how to structure such relationships[36], (also refer to EURAB, WG (Working Group) "Universities – A New Role"[37]) novel ways of working are evolving, e.g. having university departments co-located at industrial laboratories to ensure and facilitate knowledge transfer. Efforts are also being made to open up staff exchange pathways and common training programmes between industry and academia, to facilitate movement in both directions, enhance the career structures of both organisations as well as to ensure better knowledge transfer. In effect, the two SET cultures are merging at the project and research team level.

As Luc Soete has observed[38]:

"The importance of the ***local*** *environment is increasingly recognised as being the crucial factor for the 'clustering' of private research, innovation and the development of knowledge. Michael Porter and, more recently, Richard Florida emphasised the importance of local 'attraction' factors for the realisation of centres of creative activity, which no longer limit themselves to purely technological or scientific factors but now include innovation in all its creative forms and shapes. Despite the fact that the local supply of SET remains undeniably the most important determinant for the localisation of private research activities, as is obvious from the location of private R&D labs near universities and colleges of higher education/polytechnics, the demand for knowledge also appears influenced by physical, social and local, cultural factors that will in fact operate as pools of attraction in exerting a pull on highly educated people, in Florida's words: 'the creative class'. In this sense, the tendency to*

---

[36] "Researchers in the European Research Area: one profession, multiple careers", COM (2003) 436 final 18.07.2003

[37] EURAB: European Research Advisory Board

[38] See reference 33

regionally cluster knowledge centres observed both inside the US and Europe is a logical consequence of the agglomeration effects of knowledge and its appeal to researchers and entrepreneurs.

"The development of a European Research Area should provide room from this perspective for further knowledge clustering with a rise within Europe of labour mobility of highly skilled people. As a side effect, the European ideals of 'social cohesion' will come under increasing pressure."

In terms of teaching, universities are being asked to educate more people, provide a better balance of hard and soft skills, and become more competitive and market-oriented. Some form of standardisation of qualifications needs to be in place. The Bologna process can help, provided it is output standards, rather than time-serving, that provide the metric. The recommendations of the report by CESAER and SEFI offer important indicators to the way forward (Communication of CESAER and SEFI on the Bologna Declaration[39]) with credit accumulation being the important factor.

3.7 The panorama of employment opportunities

It would be wrong to imagine, however, that the expansion of SET employment will be confined to the industrial sector alone. Universities will not only be increasing their research operations in partnership with industrial firms, but will also be undertaking ever-more elaborate projects in new and old fields of 'strategic-basic' research. Newly opened domains of fundamental understanding in the biosciences are not likely to be left for exploration and exploitation solely by the United States. Nor will Europe allow itself to be left behind in fields such as particle physics and astrophysics, where it already has facilities such as CERN that lead the world.

Again, the consolidation of the EU as a single market has enhanced the need for rational, scientific regulatory systems covering environmental conservation, consumer protection, public health and welfare, etc. A large research effort, primarily within the public sector, will be required to develop and back up these systems, locally, nationally and Community-wide.

Traditional policies would continue to locate SET employment of this kind in governmental, 'quasi-non governmental', not-for-profit, or academic institutions where researchers work under typical 'civil service' conditions, with considerable personal autonomy and near-permanent tenure. On the other hand, neo-classical economics and business management theory argue for 'market' solutions where these organisations are 'privatised' and their employees are much less protected against the effects of competition and change.

It would be quite beyond our terms of reference (and capabilities) to predict the direction likely to be taken in such matters within the EU, whether for the Community as a whole or at national levels. Perhaps that is not particularly important, for the work will be done in much the same way, in the laboratory, the library or the field, however it is organised higher up. As the sociologists of science have recently pointed out ([40] [41] [42] [43]), high-quality science-based

---

[39] CESAER Conference of European Schools for Advanced Engineering Education and Research, SEFI: Société Européenne pour la Formation des Ingénieurs, "On the Bologna Declaration", Helsinki, February 2003, available at http://www.ntb.ch/SEFI/Bologna/SEFI-CESAER.pdf

[40] Gibbons, M, Limoges, C. et al. (1994), "The New Production of Knowledge", London, Sage

R&D is now ‘global’, performed mainly by multidisciplinary teams, networked electronically over geographically scattered sites, working on heterogeneous problems arising principally in diverse contexts of application, and answerable to a variety of different types of institution. Just how the members of such teams are recruited and paid for their services may be of secondary importance in relation to the overall demand for their particular skills.

The main point is that the demand for qualified SET personnel will no longer be concentrated in a few distinct sectors – ‘academia’, ‘government’, ‘industry’ – each with its characteristic research portfolios and conditions of employment. In effect, new entrants to this market place will be faced with a panorama of institutions, each with possible openings for their particular talents and ambitions. What they may not find, however, is the traditional array of conventional ‘career slots’ for which they might have thought they had been studying, and competing with their peers, for so many long years.

3.8 Market imperfections on the supply side

We now turn to the supply side of the system. It could be said, in Europe as in the USA[44], that “*the organizational structures and processes for educating, maintaining skills, and employing science and engineering talent in the workforce are diverse and their interrelationships complex and dynamic.*”[45] Broadly speaking, however, qualified SET personnel are produced by a linked chain of institutions providing school and university education in science and technology and doctoral training in research.

“When referring to the supply of SET personnel within a country, use is sometimes made of the ‘pipeline’ analogy which illustrates how, from secondary education onwards, the flow of scientifically trained scientists and engineers finally sweeps through to the various components of the R&D world in a similar way to that shown in Figure 2. A number of factors will be important in the flow of sufficient supply of researchers to, for example, the private R&D sector, despite a decreasing inflow following e.g. demographic factors at the beginning of the pipeline. Thus, there are countless obstacles preventing pupils, students, graduates, and PhD students, throughout each of the different education and training stages from continuing a research career trajectory. The Appendix to the recent Benchmark report on Human Resources in RTD[46] lists these different obstacles, the different possible policy leverages and objectives. At first sight, these seem to be equally applicable to the US than to the EU. However, it might well be argued that the decreasing domestic supply of SET workers is at the very basis of the lack of growth in business-oriented research in Europe.”[47]

---

[41] Nowotny, H., Scott, P. et al. (2001), “Re-Thinking Science: Knowledge and the Public in an Age of Uncertainty”, Cambridge, Polity Press

[42] Ziman, J. M. (1994), “Prometheus Bound: Science in a Dynamic Steady State”, Cambridge, Cambridge UP

[43] Ziman, J. M. (2000), “Real Science: What it is and what it means”, Cambridge, Cambridge UP

[44] Draft Report, National Science Board, Committee on Education and Human Resources, Task Force on National Workforce Policies for Science and Engineering, 22 May 2003, p.14

[45] SEI-2002: 2-7 to 2-15, (SEI: US Science and Engineering Indicators)

[46] See *Benchmark report on Human Resources in RTD*, DG Research, European Commission, Brussels, 2002

[47] Luc Soete (University of Maastricht), “Some personal comments on the human side of Europe’s knowledge gap”, personal communication to the HLG

In the EU, this production process takes place mainly at state expense. People emerge from it at various stages with various levels of certified competence. In most European countries there are already institutions of the type and quality required to produce SET workers formally qualified to take up all the different skilled roles currently required. But in many cases they lack the capacity to produce them in the necessary numbers, or to prepare them adequately for new career paths.

Again, as in the United States[48]:

"*The science and engineering workforce is a dynamic system, reflecting the aggregated educational and career choices of individuals, educational offerings of institutions of higher education, financial considerations in acquiring an education, guidance and career counselling to students and professionals, availability of jobs, and any number of other factors. Individual members of the workforce may enter and leave occupations several times during their working lives. Workforce needs for specific skills can rise and fall – sometimes rapidly.*

"Even within science and engineering professions and among individuals who have invested the most in their education in a given speciality, substantial changes in career paths over their lifetimes are common[49]. For example, emerging research areas attract not only newly minted PhDs, baccalaureates, technicians, and postdoctoral scholars just entering the job market, but also those who have built careers in other speciality areas. Science and engineering degree holders at all levels may go on to pursue careers in such areas as law, technical management, or university administration and move out of research and teaching. Nonetheless, they may still use the skills gained through their previous SET education and employment."

Nevertheless, according to standard economic theory, there should be no problem in supplying the necessary products. The envisaged rate of expansion is not excessive relative to the time required to train a large new cohort of researchers – say ten years from entry into higher education. School populations are buoyant and there is a lot of spare training capacity in university science departments. If more educational facilities are needed, the economic incentive to invest in them should operate on the public purse or on private capital to provide them. How is it then that there are serious fears that this clearly defined and widely advertised demand will not be met?

The answer is that the research labour market is not only complex and highly differentiated – it is also very imperfect by conventional economic criteria. These imperfections are now beginning to be appreciated, and are being flagged in various national and international reports. And yet, although many of them are both obvious and serious, they are turning out to be very difficult to correct.

The fact is that the cultural changes indicated by economic rationality are impeded by strongly entrenched, deeply rooted and tightly entangled social practices, both in the preparation of qualified SET workers and in their professional employment. These are not likely to be overcome by general policy initiatives or even by the lure of hard cash. Expansion

---

[48] Reference 37

[49] SEI-2002: 3-4 to 3-10, (SEI: US Science and Engineering Indicators)

and reorientation of the supply process thus requires a sympathetic understanding of this situation.

In brief, these practices are the living remnants of a much esteemed but now dying tradition. The education, professional training and putative prospects of researchers are still being patterned as if in preparation for careers in '**academic'** science, even though this is now only a small part of the whole system where, in fact, they will mostly work.

This is not to deny the continuing vital role of academic science in scientific and technical progress. It is just to say that it is very ill-adapted institutionally, at least in its modern European form, to the type of extensive and intensive research and development now undertaken on a large scale in the public and private sectors of our economies – even in the great research universities where it once ruled supreme.

3.9 The 'academic market place' is not a typical labour market

The way that basic research is now carried out in universities and their associated institutions no longer conforms closely to the academic 'ethos'. The customs, practices, organisational conventions, etc. that sustained the traditional 'academic market place' have been largely superseded or radically modified.

Nevertheless, many of the features of the traditional social arrangements for the production and allocation of qualified SET personnel can still be detected in present-day career patterns and structures, not only in academia but throughout the whole European research system. Furthermore, these include many of those features of the current situation that are strongly criticised in recent national reports – for example, for the UK[50]. In other words, many of the recognised deficiencies of the labour market for researchers are actually concealed legacies of the traditional academic mode of scientific employment.

It might be that the whole process should be systematically rationalised along conventional economic lines. For example, the supply of a well-qualified SET workforce could be taken out of the hands of the state and made directly subject to market forces. But that is not the way that the problem is usually posed, and we are not inclined to speculate on how it might be done. In any case, this would have serious repercussions elsewhere, especially in education.

What we would argue, rather, is that any proposed changes in the process by which researchers are educated, trained and recruited should be made in the light of this analysis, exploiting and extending the positive features of the existing system rather than trying to reshape them arbitrarily. By acknowledging some of the 'uneconomic' impediments to the flow of people into the SET workforce we are enabled to think of 'non-economic' means of avoiding them.

---

[50] The report on Sir Gareth Roberts' Review: "SET for success: The supply of people with science, technology, engineering and mathematics skills", April 2002

4 Career perspectives

Summary

There is a widely held perception that careers in science, engineering and technology are very unattractive and hold little appeal to young people. This perception covers remuneration, career structure, work environment, status and marketing. This chapter examines these perceptions as they might apply to industry, academia and government. From an industrial perspective these perceptions are not found to be true. Remuneration of SET workers is in the upper quartile of professions and the sustainability of remuneration is shown to hold for at least 11 years into their careers. It is also true that unemployment amongst holders of SET tertiary education qualifications is lower than that of the population at large. The diversity of careers for people with an SET background is shown to be great and probably far more varied than any other sector. Taking all these aspects into account, it is difficult to understand why there are such difficulties in recruitment. The conclusion has to be that industry and the profession are not selling careers in SET in the most attractive fashion. This is certainly an area for future attention.

Despite the risk from employment uncertainties – an aspect which must be true for every sector of the economy these days – industrial careers are shown to contrast with careers in academia and the public sector. Remuneration here is poor and career structures are not conducive to attracting both the quality and quantity of qualified people that are required. Although there are other aspects of employment which do attract people to this section, they are not enough to tip the scales in favour of large numbers of people wanting to enter these professions. This is certainly an area that needs the full spotlight of national and European policy to be directed towards it as there are serious deficiencies now that need to be remedied. This chapter discusses these in full.

There is a general conclusion that the main emphasis on closing the 3% gap lies mainly with industry, so industry needs to promote careers in a more attractive way to prospective SET employees. However, it is not a job for industry alone. National governments as well as the Commission have a significant role to play and it is only through a coordinated approach that the problem can be solved. Good, well-remunerated, attractive careers in the public sector and academia need to be in place and marketed as such to future generations if the entire ERA and knowledge- based economy are to be fully realised. This is absolutely key to the future prosperity and competitiveness of the European zone.

4.1 Images and realities

Any questioning of the diverse roles of the SET workforce in European life and work lies far outside our Terms of Reference. Nor is it our responsibility to comment directly on the organisations and institutions through which these roles are coordinated and activated. Nevertheless, in considering how to enhance the recruitment of professional researchers and other qualified SET workers, we cannot overlook the conditions under which they are currently, or are likely to be, employed.

Sir Gareth Roberts remarks[51]:

"According to a recent report[52] for the Office for Science and Technology, men and women holding SET degrees had initially chosen to work in SET occupations because they had enjoyed their studies. Those that continued to work in these occupations preferred the work because they found the work was varied, they enjoyed problem solving, they were not office bound and there were travel opportunities on offer. Those who disliked working in SET occupations found that their job was boring and repetitive, and they had little control over what they did and how they did it. They complained about poor working environments with little human interaction, not being able to see immediate results from their work, and about low rates of pay."

But these are relatively local, short-term impressions, not life-cycle assessments. Realistic *career* perspectives are particularly important because of the very long time that can elapse – of the order of ten years in many cases – between a personal commitment (or at least an aspiration) to become an SET researcher and the actual moment of entry into professional employment. The act of 'recruitment' is not really, for instance, acceptance of a junior research post in a university, research organisation or industrial firm. By that stage, there seem few alternative careers worth considering. In effect, the recruitment process often starts at school where the choice of subjects for the baccalaureate qualification already keeps open or closes off this option, and is steadily reinforced (or aborted!) through the successive stages of education and training.

It is quite possible, of course, for this initial choice of a career, and the further choices that branch off from it in the course of higher education, to be based upon entirely misleading conceptions of what it will be like in practice. But when this happens – i.e. when, for example, a fully trained 'doctor' of 30 is deeply disappointed by, and disaffected from, professional research work – it is more than a personal disaster, a waste of educational effort, etc. It is also extremely damaging for the public image of SET work, and thus highly prejudicial to the recruitment of young people to this putative career path.

Throughout, it must be assumed that young people will make rational choices based on the situation as they see it. If people with innate ability choose not to follow courses and careers in SET, then their reasons must be understood and addressed. It is not enough to try to convince them that they are wrong. These perceptions start at a very early age and are reinforced by general societal values and by the success or failure of those they see around them.

- Issues of remuneration, and perceptions of status and self-worth need to be addressed.
- Whereas average industrial wages in SET are generally competitive, academic jobs are not well paid and are less secure than in the past.
- Further, there is often the perception that industrial jobs will be risky and insecure, or simply not offer people the chance to make the contributions they feel capable of making. It is clear from speaking to both young people and academics that today's

---

[51] The report on Sir Gareth Roberts' Review: "SET for success: The supply of people with science, technology, engineering and mathematics skills", April 2002, section 3.72, p. 105

[52] "Maximising Returns to Science Engineering and Technology Careers", prepared for the Office of Science and Technology by People, Science and Policy Ltd and the Institute for Employment Research (University of Warwick), January 2002

business models based on management progression, technology integration, and company acquisition are treated with great suspicion in Europe.

- It should be possible to overcome these perceptions, provided that there is a general willingness to listen while accepting that the world has changed, and that companies and universities are giving more attention to demonstrating what people actually do in an industrial career. This evidence has to be available at a sufficiently early stage, before decisions are cast in stone.

4.2 A diversity of models

SET careers are followed in such a wide range of organisations, at such a variety of levels of responsibility, in so many specialised roles, that it is difficult to generalise about them. Indeed, recognition of this diversity of career models – a diversity that is on the increase – is one of the keys to increasing recruitment to the SET workforce as a whole. It permits much more actual flexibility and adaptability in personal career trajectories than seems possible from the conventional viewpoint at the bottom of the ladder.

It is wrong to suppose, for example, that real job responsibilities in R&D are rigidly graded in terms of formal academic qualifications. Thus, the widespread notion that one can only become a 'researcher' by taking a PhD is mistaken. Quite a large proportion of the professional scientists and engineers working in R&D organisations have entered without this degree, and although many of them acquire all the prescribed knowledge and research skills 'on the job', they do not all find it necessary to submit themselves later for formal examination.

On the other hand, as Roberts emphasises[53]:

"*Training and continuing professional development are vital to staff in fast-moving scientific disciplines, and act as an important retention mechanism. However, science and engineering graduates are offered less job-related training than those from other disciplines.*"

Even in academia, where a higher degree is effectively obligatory for a senior post, many competent and experienced full-time SET employees are also registered as 'graduate students' working for doctorates – although they often find difficulty in setting aside the time for advanced study, writing a dissertation, and so on. Active encouragement and practical facilitation of these procedures – for example, by the provision of 'time off' and systematic training in specialised subjects – would open up new career opportunities for many SET recruits.

Should this policy of stimulating the upgrading of personnel be applied more vigorously at lower levels in the system? As we have observed, a substantial proportion of the SET workforce enter employment either from cognate disciplines, or with no more than 'vocational' qualifications – typically at or below baccalaureate level in academic terms. Nevertheless, some of them acquire skills and responsibilities, especially in 'technical' roles, that easily surpass 'professional degree' standards. Should much more provision be made for in-service training, courses of further and higher education, 'external' degrees, etc. to qualify them formally for the higher ranks of the research system? Jane Goodall, who began her

---

[53] Roberts (ref 1), p.173

world-famous research on primate behaviour as a secretarial assistant, could be an inspiring model for just such a career.

The diversity of careers for people trained in SET is wonderfully varied but little is done to exemplify and promote this variety. In Figures 1 and 2 we can show the various career structures envisaged for engineering and physical science graduates.

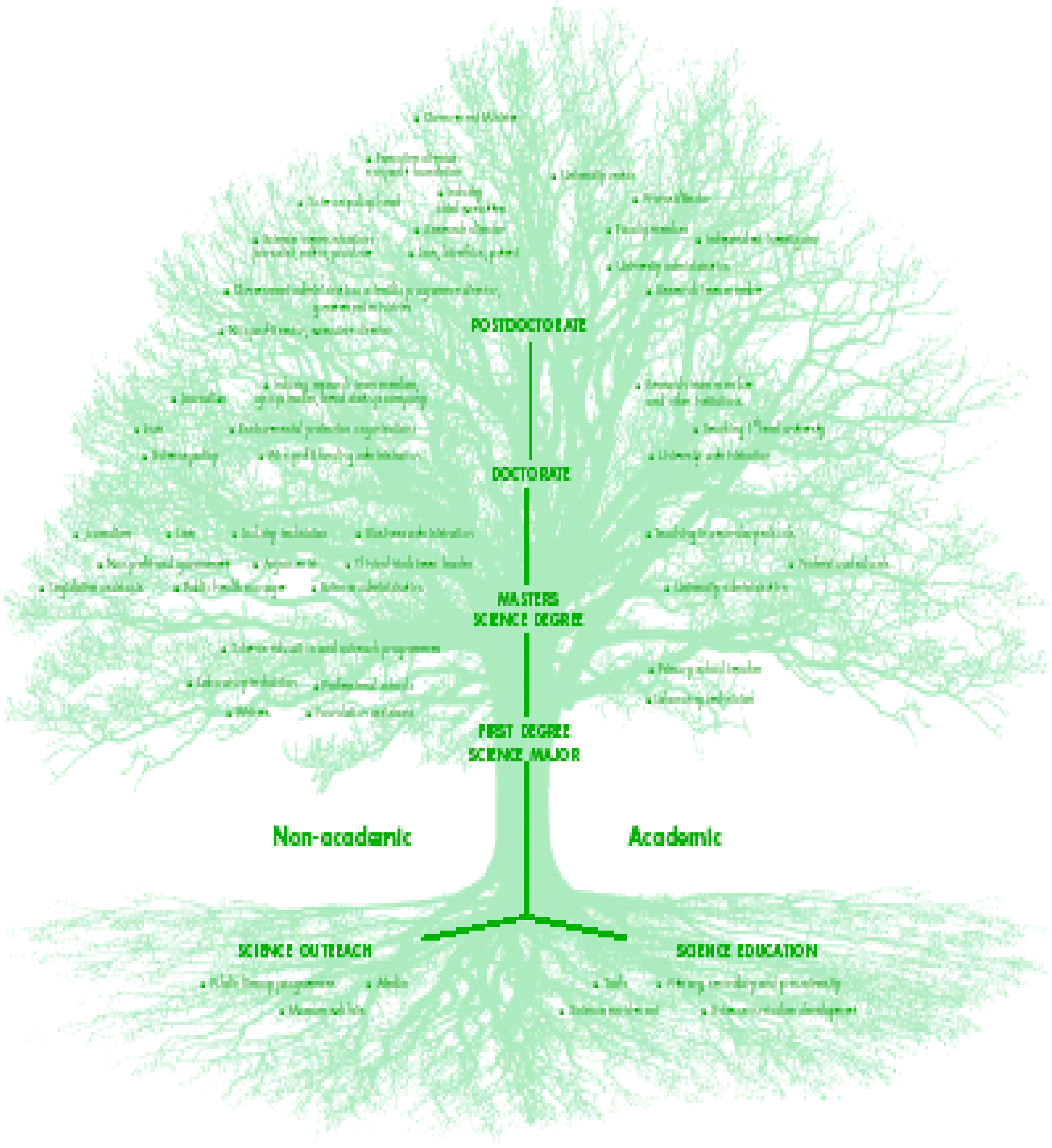


Figure 1. **Career structures as envisaged by the ESF. (Source: ESF Policy Briefing "Towards a new paradigm for education, training, and career paths in the natural sciences", July 2002)**

The tree visualises science training and careers as a rich, ramifying, highly permeable network of roots and branches reflecting the broad range of inputs into the science arena and the wide range of opportunities for those who receive training in science and engineering. This tree has a width equal to its height, strengthening the image that the network leads to a wide range of valued careers some of which are directly involved in scientific research while others are associated in varying degrees and could be found in areas including schools, administration, government, the media, finance, and many other domains.

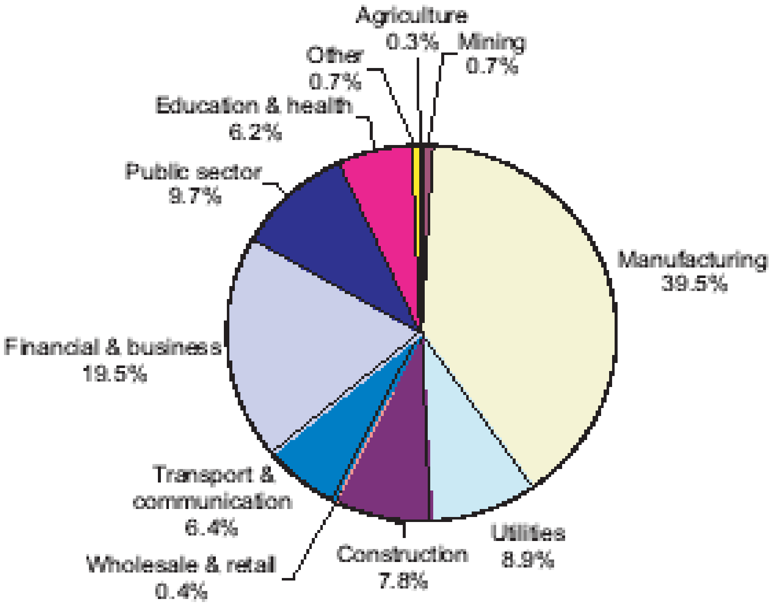


Figure 2. **Employment of registered engineers by industrial sector in 2002. (Source: Engineering Council UK)**

At the top of the ladder, where there never seem to be enough suitable candidates for the posts on offer, it is all too easy for good people to move out of 'productive' SET work. This is not to deny the value of the managerial, administrative, official, 'political' and other non-research functions performed by successful research scientists. In fact, it is to be applauded, as SET people with influence over the political, financial and business scenes are valuable to the promotion of such careers and encourage more people into SET. But it is nevertheless costly to the SET workforce if productive researchers are induced to transfer prematurely to 'management' career tracks by prospects of better pay and higher status. In other words, the diversity of possible careers should apply even at the highest levels of SET achievement, with goals of comparable esteem for outstanding researchers and research leaders (as distinct from company directors, senior civil servants, government ministers, etc.) across all the different sectors.

4.3 Features of academic research as a career

Scientific research has been undertaken in a great variety of forms and societal modalities, and has changed considerably in its social practices over the centuries. This is a highly schematic and oversimplified account of a very complex social institution. But it provides clues to what are otherwise very puzzling features of the present system. Consider the following:

4.3.1 Low starting pay

Postgraduate students, postdocs and junior academic staff are notoriously poorly paid, both relative to their contemporaries in other professions and absolutely in terms of the quality and quantity of the work they do. The accumulation of personal debt is not untypical at this stage. This is because, although they have passed through a highly selective hierarchy of examinations, they are still considered to be apprentices to their craft. They are thus deemed to be sufficiently privileged by having the freedom to do the research that will be needed to make a good showing in the final competition for a tenured academic post. One such example can be found in German academic tradition, where a *privat dozent* was expected to have the means to support himself into his forties before winning a regular professorial chair. Even now, a short-term, postdoctoral ‘fellowship’ is considered to be ‘prestigious’ in terms of future achievement, and thus to require scarcely any monetary incentive.

4.3.2 Limited material rewards

Even when they are fully established in permanent jobs, in academia and elsewhere, researchers are not highly paid in comparison with people of similar standing in other professions. Apart from a few celebrities, they are not steeply differentiated in terms of salaries. This is partly because their guild tradition is of relative equality and collegiality in the senior strata. It also derives from the notion of science as a genteel calling, activated by personal dedication and zeal for the truth rather than by material incentives. The tradition of the *savant* as an obsessive *amateur* undertaking research in his own time and his own expense still prevails in some circles, and may account for the remnants of gender, class and ethnic discrimination in the research professions. For this reason, efforts are made to persuade young people to enter science primarily for its psychic and moral rewards – the excitement of discovery, the fascination of problem solving, the virtues of knowledge production – rather than for the normal professional rewards of an interesting job, a good income, and respected social standing.

4.3.3 Top-down curriculum design

The education curriculum is still designed ‘from the top down’, as if entirely for the ten-year process of generating successful doctoral candidates. But the students who actually complete this course comprise less than 10% of the pupils who voluntarily enter science courses at secondary school. Little account is taken of the career and societal aspirations and circumstances of the remaining 90%. School and university curricula in science are thus considered by the majority of students to be unattractively rigorous, formal and ‘academic’.

4.3.4 Teaching in terms of academic disciplines

Science curricula and teaching processes are broken down into ‘subjects’ and ‘disciplines’ that correspond to the academic classification of the sciences into research specialities. Students are taught nothing of the diverse, technically fascinating, and socially invaluable interdisciplinary problem areas where much new and groundbreaking R&D is undertaken. This is because the only way to enter academic employment is by specialised research in an already recognised field – so these are the fields that, in general, are taught to undergraduate students.

4.3.5 Specialisation in research

For postdoctoral workers, this hard-won specialised perspective is such a valuable personal investment that it usually persists for the remainder of their careers. Researchers become so identified with their specialities and so ‘locked into’ their established fields of research activity that they find it exceedingly difficult to move into other fields. Academic science thus has no systematic procedures for the retraining and redeployment of its members in order to meet the human resource needs of rapid scientific and technical progress.

4.3.6 Individualism

The focus of students and teachers on achieving personal success in competitive examinations fosters a degree of individualism which is not consistent with the teamwork that has always been required in most industrial R&D. The ‘creative’ style of individual achievement, which is encouraged and favoured in postgraduate and postdoctoral work, is also antithetic to formal training, so that apprentice researchers often resist instruction in the basic theories or broader context of their field of research. They and their research supervisors are even more resistant to their ‘taking time off’ from their research for training in the elementary teaching skills required of most academic scientists and in the managerial skills and responsibilities likely to be needed by the high-flyers in research careers outside academia.

4.3.7 Intellectualism

Competitive achievement in an educational setting is most easily (and cheaply!) fostered and assessed in ‘intellectual’ terms – that is, by the ability to master complex factual material, grasp the significance of theories, solve formal analytical problems, etc. Success comes to students and research apprentices who shine at theoretical work, especially mathematics. Science curricula, courses of study, examinations, etc. thus systematically underplay, neglect and even totally omit the practical work, in the workshop, the laboratory and in the field, that is a major component of the research process, and give little credit – that is, little opportunity for recruitment to high-level research employment – for the achievements of young people with relatively ‘non-intellectual’ talents.

4.3.8 The invisible human substrata of research

Academic careers are traditionally shaped by ‘attrition’. The meritocratic competition for entry into and preferment within the research élite lasts for 20 years. At each major stage of selection, the majority of the candidates fail to make it to the next stage, and vanish from the scene. Most of these, however, do not ‘drop out’ of science entirely. Indeed, in many business enterprises it is people with bachelor degrees who actually carry out most of the research and who often rise to high managerial posts. Many others are employed as technicians, schoolteachers, research assistants, technical sales staff, information officers, etc. The skilful, responsible performance of these jobs is vital to the functioning of the research system, yet they are considered much less prestigious than research itself. In particular, the 'technical officers' and 'research associates' who run sophisticated experimental apparatus in universities and research institute science are effectively 'invisible' to academic eyes.

4.3.9 Science in vocational education

The training of many of the junior support staff in research is actually carried out as 'vocational education' in extremely practical institutions such as 'technical colleges', where a watered-down version of elementary academic science is taught largely by rote. For technical staff requiring a higher level of scientific understanding, this need is supposedly met by what has been learnt, not very successfully, in a segment of a standard academic curriculum designed for future researchers. As a result, the majority of students of the sciences, at school and university, are undergoing instruction that is entirely uninspiring, or that is not specifically designed to help them professionally in the careers they will actually practise. In this respect, research differs significantly from other high-level professions, such as medicine, architecture, law, etc.

4.3.10 Career planning and counselling

Long-term career planning and counselling is made very difficult by competitive attrition in science education and research training. Undergraduate students, graduate students and even postdoctoral workers cannot plan or be advised on their career choices more than a year or so ahead because these are subject to the uncertainties of examination success, PhD thesis progression, or short-term contract research. Thus, although the most likely – and socio-economically valuable – career prospects for an undergraduate student of modest ability might be as a technical officer in team-research in industrial R&D, he or she cannot plan a course of study designed for such a career in a context where individual prowess in academic research is the ruling paradigm. Again, at the postdoctoral level, although it is well known that personal patronage by senior scientists plays a vital part in the career advancement of their former students, the traditional doctrine of 'academic freedom' is often interpreted to exclude systematic procedures for monitoring, managing, developing, reshaping or even assisting individual scientific careers.

4.3.11 Career immobility

Academic science is famously 'universal'. In principle, and to a considerable extent in practice, researchers are interinstitutionally and internationally mobile, especially at the postdoctoral level. Nevertheless, 'established' researchers, especially in public-sector institutions, are often discouraged from moving elsewhere by 'tenure' and pension rights. As noted above, there are also very strong customary constraints on movement between disciplines. Upward or sideways career moves into quite different types of employment, such as academic administration, full-time teaching, professional consultancy, or business management, are not the norm. Nor is it usual for individuals to enter academic research in mid-career – for example, through transfer from technical support work, professional practice or even industrial R&D. Academic science is meritocratically open at its early stages, but it is very rigid and highly stratified overall, and has no regular procedures for upgrading its non-research personnel to responsible research posts in mid-career.

4.3.12 Vestiges

This list of some of the career aspects of academic research is obviously greatly simplified. The way that basic research is now carried out in universities and their associated institutions no longer conforms closely to the academic 'ethos'. The customs, practices, organisational conventions, etc. that sustained the traditional 'academic market place' have been largely superseded or radically modified. However, there are vestiges of them that still persist as ideologies, even though they are no longer socially operational. They can therefore impede the transformation to a more realistic image of the nature of a SET career. Many of these features are strongly criticised in recent national reports – for example, in the UK[1]. It is argued that changes to the process by which researchers are educated should be made in the light of this analysis, exploiting and extending the positive features of the existing system rather than trying to reshape them arbitrarily.

4.4 Salaries and other tangible rewards

On the whole, the SET workforce is adequately, but not handsomely, paid. Indeed, relative to callings of comparable mental challenge and length of education, they are probably somewhat underpaid. However, from a study by the Engineering Council (UK)[1], first-time graduates with engineering qualifications are among the best paid of all professions, bettered only by those in law and clinical dentistry. This is not well understood by students when choosing careers at pre-university stage. Figure 3 illustrates the sustainability of SET careers, the data showing that 11 years into their careers, engineers continue to perform well above the average professions in terms of remuneration. Figure 4 shows that people who have completed SET tertiary education are in demand in the employment stakes with very low unemployment rates being recorded by graduates in recent years. In a similar vein, it can be seen from Figure 5 that people with higher degree qualifications attract a premium for their studies, which shows tangible rewards in terms of salary over most other professions[1]. Much should be made of these facts, to counter the general public's perceptions that SET workers are poorly paid. In addition, SET workers are not motivated by financial rewards alone, and are generally not dissatisfied with the level of remuneration. In general, there is high level of job satisfaction within the SET career structure.

---

[1] Sir Gareth Roberts, "SET for Success", April 2002

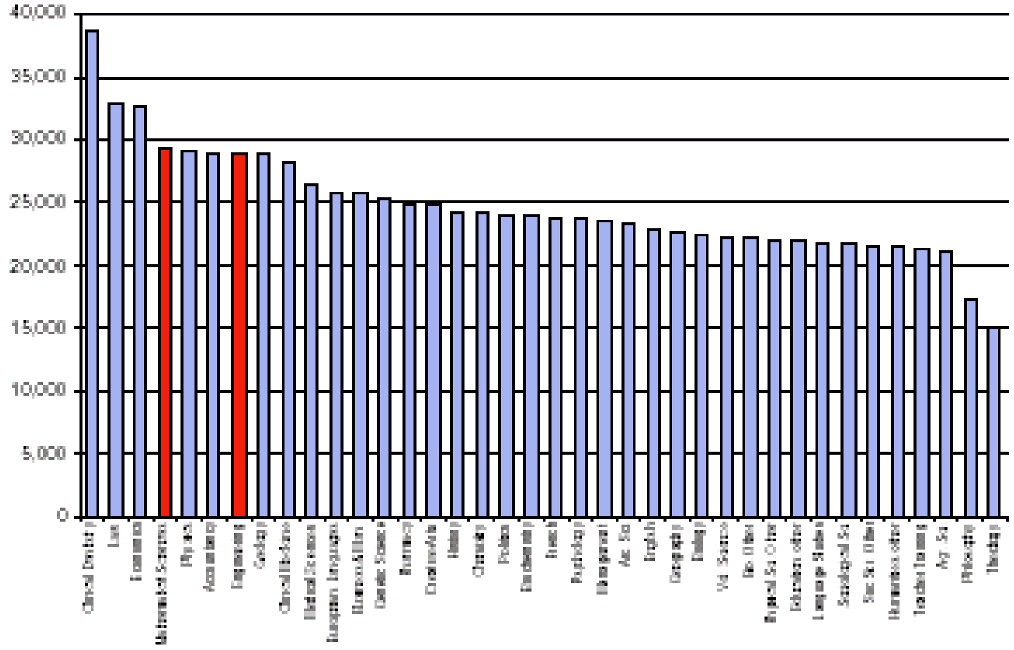


Figure 3. 1996 salaries of 1985 graduates by degree subject (£). (Source: “Engineers for Britain”: The state of the profession towards 2002, Engineering Council,UK)

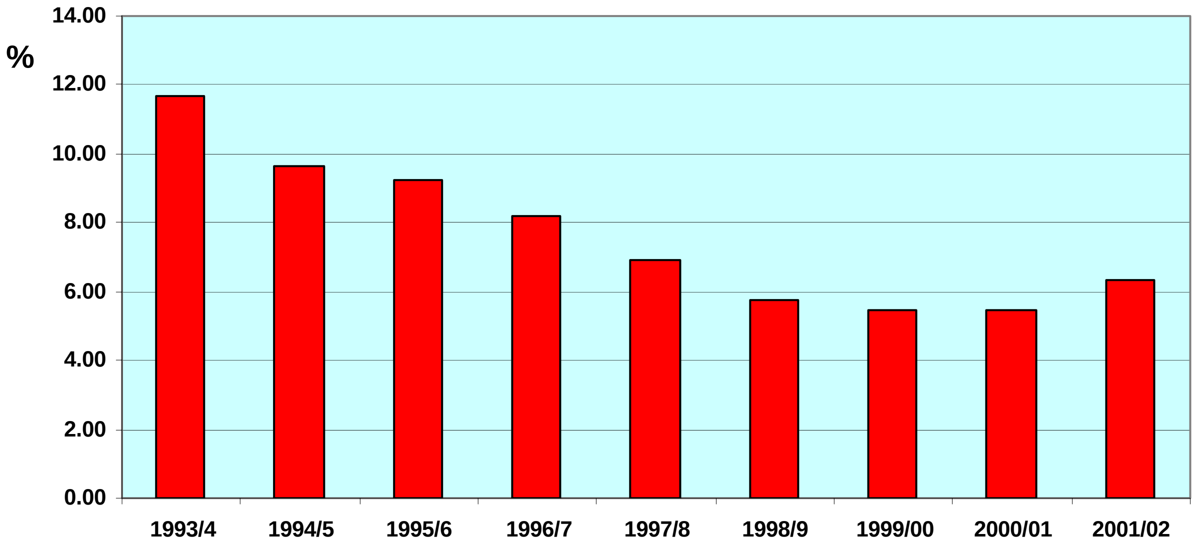


Figure 4. Graduate unemployment 1994-2002. (Source: AGR/AGCAS/UCAS/CSU, 2003)

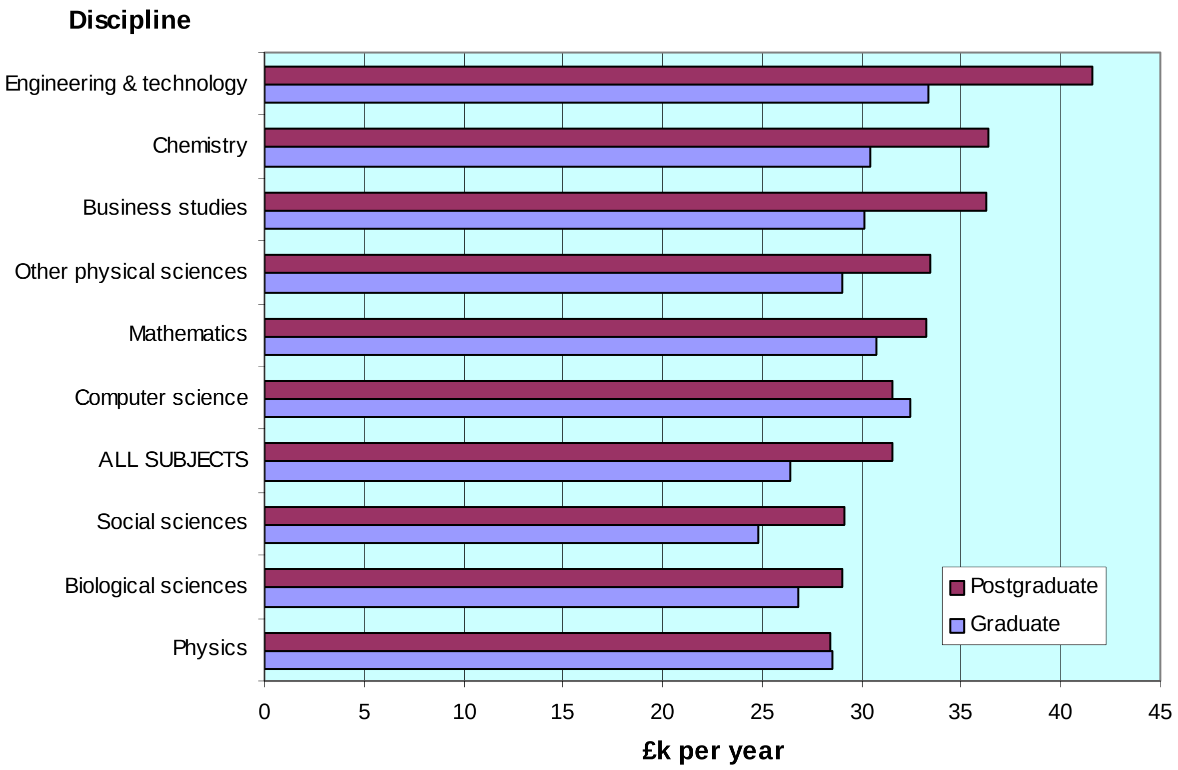


Figure 5. Gross annual pay in main job by discipline and level in 2001. (Source: Sir Gareth Roberts, "SET for Success", April 2002)

It is accepted that industrial SET workers earn rather less than the value that they actually add to the output of their companies. This begs the question why do they not use their collective power to bargain for more? Again, even when SET labour is in short supply in particular fields, salary rates do not rise proportionately. At most, people are promoted to higher, better-paid grades, but that may be because these have to be filled, anyway.

There is thus a contradiction between the claimed shortages of SET personnel in the private sector and the fact that the SET salaries of that sector – at least compared to other professional groups – do not seem to reflect such shortages. It is interesting to note that during the dot-com boom when IT specialists were much in demand, salaries for new graduates were inflated by just ~10%. It was only the very experienced operatives, who were few in number, who experienced large salary increases. So the market pull was in evidence but not to the extent one might have expected. This could be due to the cushioning effect of SET salaries in the public sector, but it might also be a reflection of the fact that the private sector does not value technology and research today sufficiently highly and is now giving much stronger incentives to managers, financial analysts, marketing managers, accountants, auditors, etc.

An alternative explanation may be that most researchers quite enjoy their work, and do not do it just for the money. This is another manifestation of the characteristic 'imperfection' of the SET labour market. The work to be done is highly specialised. Such supply as is available comes forward at a lower price than it 'ought' to, so wages are not inflated.

There is a contrast here with the US. It seems that the typical European researcher, or the European youngster interested in SET, is much more influenced by non-pecuniary considerations in choosing a research career. Shortages on the private- sector side in European

SET may reflect a preference for an academic or public research career, rather than one in industry.

As a consequence, SET workers in industry are attributed with the social status thus indicated – i.e. somewhat lower than their labours deserve. Locally, in the short run, this may not seem unreasonable or unjust. But it is a closed socio-economic loop that keeps both pay and status down. In the long run, it can lead to chronic shortages of qualified researchers by driving recruits away from what is perceived as a relatively undervalued profession. Given the efforts needed to be put into their education and training, the rate of return on such heavy studies is insufficient both in pecuniary terms and in terms of career perspective. From this perspective, management, finance, accounting, and marketing studies are much more rewarding, with more promising and, in the end, interesting career opportunities. As Roberts points out[54]:

"*Although businesses in the financial services and similar sectors may not give a substantially higher starting salary to the average graduate, they will pay considerably more for a highly skilled graduate than R&D businesses. Furthermore, the salary progression is far more rapid in the financial services sector than in industrial R&D.*"

The situation in the public sector and in academia, as described earlier, is somewhat different. Researchers there are not engaged in work that can be directly evaluated economically, so there is no better guide to wage rates than market supply and demand. On the one hand, the generally attractive nature of the work and conditions of employment draw in a surplus of candidates ready to work for relatively low pay. On the other hand, this work requires such specialised skills that there is competitive bidding for those deemed best able to perform it.

As a consequence, starting salaries in academia are notoriously low in comparison with other skilled professions, and even academic staff with permanent positions take many years to 'catch up' with their contemporaries in medicine, law, the civil service, etc. Loss of excellent, very experienced researchers to non-research posts or to jobs abroad is a major concern in many European universities.

However, what is more serious is that in some countries many experienced researchers with doctoral-level qualifications spend a substantial portion of their careers in a succession of low-paid, short-term 'contract' posts in the hope of obtaining a permanent academic position. Although this is sometimes described as 'postdoctoral training', it is seldom systematically organised or combined with other modes of professional development that might prepare them for careers in other sectors. In some cases it lasts into mid-career and beyond, and thus has a generally depressing effect on career prospects and wage/age profiles in university research as a whole.

It can be argued that this provides the industrial and public sectors with exceptionally highly trained researchers who are eventually induced financially to move out of academia. But by this point they may not really be as well-suited to these other modes of SET work as people who were recruited earlier and who have acquired the necessary knowledge and skills 'on the job'.

In other cases, contract researchers stay in academia by taking positions in less-prestigious universities where their research output is limited by poor facilities and heavy teaching loads.

---

[54] Roberts (ref 1), p. 170

This, again, may be an appropriate way of staffing higher education with research-trained personnel, but it tends to downplay the value of the teaching which is the principal function of such institutions. As even the most senior academic staff of highly esteemed ‘research universities’ know from personal experience, good undergraduate and postgraduate teaching is very labour intensive. Traditionally, however, it has gone along with research and other forms of scholarship in a mutually fruitful combination. Thus, the separation of academic personnel – even of whole institutions – into ‘researchers’ and ‘teachers’ is not necessarily beneficial to the SET system.

In other respects, “*it is undoubtedly true that many long-term contract researchers have tried and failed to obtain appointments as academic staff. However, other CRS see their roles as skilled research workers, and have no desire to teach or to fulfil any of the other obligations of the typical academic. Both groups are concerned that their research is not perceived as valuable, and that they are marginalized and expendable. Perhaps as a result, a number become disillusioned with research as a career.*”[55]

To sum up, as is now widely recognised, contract research is a feature of SET employment that significantly affects the expansion of the SET workforce. It seriously reduces the attractiveness of a research career, as perceived realistically by young people who are unsure how high they are likely to fly in this very competitive segment of the profession, yet it permits career trajectories to deviate for significant periods from what might have been much more productive paths.

4.5 Stability and/or opportunity

Traditionally, one of the most attractive aspects of a research career was stability of employment. After a strenuous period of doctoral training and competition for a post, a researcher could settle down for life in a university, a public research organisation, or a large industrial firm. Academic and civil service tenure was largely matched by permanent employment contracts in the private sector. Of course, people were motivated to work hard for promotion to higher ranks, but they could feel secure enough not to worry about their basic jobs.

For various reasons, this situation has changed. Academic tenure comes later in a career, if at all, whilst large industrial companies are downsizing their in-house R&D facilities, and contracting out much of their SET work to smaller firms with much higher rates of labour turnover. Indeed, much of their strategic-applied research is being performed in universities by ‘contract researchers’ with no long-term job security. In effect, universities are exploiting the desire of many professional researchers to stay in an academic environment to save themselves the long-term expense and staffing rigidities of giving them permanent employment.

Since salaries in industry remain more or less competitive, scientists and engineers can move freely into the financial and businesses sectors where their training and skills are much prized. This is not to be seen as a loss to SET: the more such transfers occur, the more the value of SET to all sectors of the economy.

---

[55] Roberts (ref 1), p. 148

Nevertheless, there is a widespread perception that industrial jobs will be risky and insecure, or simply not offer people the chance to make the contributions they feel capable of making. It is clear from speaking to young people and also academics that today's business models based on management progression, technology integration, and company acquisition are treated with great suspicion in Europe.

By contrast, however, public-sector research jobs remain fairly stable, perhaps because much of the work they do, such as environmental, health and consumer protection and regulation, is not subject to market competition or to the vagaries of intellectual fashion. Does this now give them an advantage over the other sectors or does it limit their attraction as careers for enterprising young people?

Much of the SET workforce in Europe will continue to be absorbed in the public sector. European policy-makers should therefore give more consideration to providing entrepreneurial opportunities in this sector. They might, for example, encourage public research organisations and universities to create spin-off companies and other techno-starters, thus realising the economic externalities of public research, rather than just looking at incentives for the private sector.

Overall, career stability and security would be enhanced if it were relatively easy to move between similar jobs in different sectors, particularly in countries/regions/
sectors with an imbalance between the two. And yet, as pointed out by **ERA**[56]:

"*In recent years, social, political and financial pressures have grown to justify the practical relevance of research carried out in academia. Despite these changes, in many fields applied research projects are still granted a lower status, and academics involved in industry are not seen as serious candidates for academic promotion. In such a context, a job in industry may be regarded as a second-class option and, equally, the formal requirement (a doctoral degree) for academic positions makes it difficult for industrial researchers to move to academia. Issues, such as the transfer of pensions and social security rights, the loss of acquired benefits and professional status, the totally different cultures regarding on the one side confidentiality of research results and intellectual property protection and on the other publishing, also make it difficult to move from one sector to another.*"

4.6 Autonomy

In a sense, this emphasis on individual *commercial* enterprise is not new. It replaces the traditional stress on *intellectual* enterprise that was always a driving force in academia. One of the features of SET careers nowadays is that, unlike before, they do not allow much room for individual autonomy until much later in life. A few academic high-flyers still win prestigious fellowships where they are free to undertake projects of their own choice. But the majority of doctoral students, many postdoctoral workers, all 'contract researchers', and the junior grades in public-sector and industrial research organisations have very little of the individual autonomy that has always made research careers so attractive.

This freedom does come, eventually, to those who lead the research groups and teams that are now the work units of SET activities. But it is no longer one of the defining features of a

---

[56] ERA: "Researchers in the European Research Area: one profession, multiple careers", COM (2003) 436 final 18.07.2003, p. 10

professional research career. The expansion of the SET workforce will mostly require expert teamworkers trained to co-operate fruitfully with others, rather than extreme individualists who plough on independently along their own specialised furrows.

Notice, moreover, that although SET careers are not likely to become less specialised, individual by individual, they will not be so easy to define in terms of conventional academic disciplines and sub-disciplines. Team research is often more *interdisciplinary* or even *transdisciplinary* than *multidisciplinary*. That is to say, although individuals come into the team from different SET traditions, they do not necessarily each operate within the constraints and paradigms of their particular discipline in the context of the research project. They develop their own specialised techniques and take on their own particular role within the team as a group, and carry this experience further in the course of their career. In other words, they will be better prepared for the realities of a research career if they have already had some experience of this way of working.

The romantic image of the researcher as a lonely ‘seeker after the truth’, scarcely concerned with material rewards, is still widely promoted. And yet for the great majority of potential scientific workers it is so obviously unrealistic that it may serve mainly to obscure the attractions of an equally deserving career as a highly skilled professional worker operating in an organised team to solve difficult but interesting technological problems.

5 Higher education and research training

Summary

There is a need for higher education institutions to shift their scope and mode of operation from preparing experts for an industrial society to educating reflective personnel capable of contributing towards meeting the needs of a knowledge society. For instance, instead of presuming that all their SET students are headed for academic careers, universities should cater for and celebrate the whole range of research employment, including the relatively less prestigious jobs that many of their graduates will actually be taking. Curricula should be less ‘theoretical’ and should more directly reflect current societal SET needs. Important job skills for all employment sectors include writing, oral presentation, management, data analysis, project design, critical thinking and collaborative work, and the ability to handle uncertainty in an interdisciplinary context. Research training in association with and opening into industrial R&D might also take the place of doctoral and postdoctoral programmes for many graduates. Full access for women and ethnic minority groups to courses leading to research careers should be further emphasised.

The involvement of undergraduate students in research activities as a normal part of their curriculum is still very exceptional. Opening research laboratories and industries to the undergraduates in SET would promote a more realistic perception of research by students and could effectively contribute to rapidly increasing human resources for SET in Europe.

5.1 Higher education institutions and systems

The production of qualified SET workers is carried out by **higher education institutions** – typically **universities** – that take young people leaving school, designate them **students**, interact with them for a few years – typically three or four – and turn them out as **graduates**. Some of these undergo **postgraduate** training in research and graduate with advanced degrees, such as doctorates.

Each European country has its own national **system of higher education**. These are the unique and indispensable means by which researchers are produced. They are continually subjected to criticism – by their students, their staff, governments, business, the media, the public. However, they are so large, so complicated in detail, so different from country to country that it is difficult to generalise when referring to them. Consequently, it is very difficult to suggest, or agree on, general ways in which they might better perform their allotted functions.

Thus, the standard response to the challenge of producing large additional numbers of SET workers is to ask for the means to expand the system proportionately. Indeed, in many countries, universities have been under severe resource strain for many years. So it would appear that the first thing to do is to pay the present staff adequately, hire enough new ones to do the enlarged job properly, and provide them with the necessary infrastructure, including buildings and laboratory facilities. It would be a false economy to try to fill the gap with people educated or trained much more cheaply, to a much lower standard of performance.

Unfortunately, this conventional policy would probably fail. The fact is, as we reported in Chapter 2, the deficiency nowadays is in the supply of would-be SET students, not in the facilities for educating them and training them in research. In the next chapter we will look at school education in that light. But the real challenge to the European higher education system is to ensure that the cohorts of young people who do enter our universities annually as SET students come out of them properly prepared, qualified, informed and motivated for entry into the increasing number and range of SET careers that will soon be opening for them.

For that reason, the emphasis in this chapter is less on the quantitative aspects of the system than on the need for qualitative, structural changes. In essence, universities should be providing students with the knowledge – including the skills required for their actual career paths which are very varied – rather than for the idealised *cursus honoris* of the selected few who aspire to academic careers in pure science.

Specifically, there is a prevalent paradigm that is recognisable in most universities independently of the widely varying educational contexts. This paradigm conceptualises university education as a mechanism for disseminating established and undisputed knowledge, usually organised in the respective disciplines. The system strives for gifted individuals presenting lucid explanations of the essential aspects of this established knowledge, and departments organising various forms of activity to gain experience in practising this knowledge (such as tutorials, laboratory sessions and seminars). The few students who flourish in this paradigm can aspire to become charismatic teachers themselves with opportunities for participating in the production of new knowledge. The assumption is that people who do not quite make it in this context can fulfil the more mundane research needs of industry or other non-university establishments. This paradigm, including the content-delivery model of teaching that is associated with it, was designed for an industrial society where few positions of employment require original and creative thinking and most people find employment in roles performing routine tasks which only require basic skills spontaneously developed by all. The established paradigm is poorly suited to the needs of a knowledge-based economy, where original thinking and creative work are expected of the many rather than the few.

5.2 Higher education in the knowledge society

Sustainable development in Europe will rely on the development of knowledge societies in the coming decades. It is thought that for the production of primary goods, manufacturing and assembly work can be undertaken more efficiently in other areas of the world. Europe will instead have to concentrate on design, creativity, innovation and the creation of new markets. The European knowledge societies will need robust innovation systems, information and communication infrastructures and, lastly, lifelong education and continuous development of the human resource.

Knowledge will gain increasing importance but, more important than that will be the processes of science as the mechanism for producing new knowledge and making knowledge usable. Knowledge institutions will be future-oriented, self-developing and active, ranging across traditional disciplinary boundaries. Associated with this is the ideal of creating a knowledge society throughout which there is a widespread commitment to continuous learning for personal, economic and social well-being. The Bologna Declaration, the subsequent process and the ideal of a European Research Area demonstrate that there is political will to institute the policies that will make the knowledge society scenario more plausible.

Although in the EU tertiary education accounts for 1.1% of GDP, and R&D expenditure for 1.9%, the corresponding percentages are 2.3% and 2.7% in the USA. The value added by the services of higher education and research as a share of total value added represents some 3% in the EU and 5% in the USA.

Higher education contributes to the supply side of national well-being in that it contributes to the formation of graduate human capital. The proportion of Europeans with a higher education qualification is increasing as an increasing proportion of young people enter higher education – there were 12.5 million higher education students in Europe in 2000, compared to fewer than 9 million in 1990. One-third of Europeans work in highly knowledge-intensive sectors[57], more in some countries.

Higher education produces very diverse outputs. Some can be quantified through economics; others are more intangible, but generally essential for economic and social welfare. The agents of development are heavily loaded with human capital of exceptional characteristics, and are far from homogeneous. Institutions looking for economies of scale or scope have to find ways of increasing the productivity of teaching and research.

During the past three decades, European higher education systems, and especially public universities, have started to change under the pressure of many events and trends, such as economic globalisation and information and communication technologies. The main changes relate to the emphasis on accountability and the strife of higher education to make use of public budgets in order to respond to real social needs. In particular, higher education is becoming increasingly shaped by new market demands in relation to the need to integrate education and training and to bridge research to innovation and technological development. Higher education systems have become more open. The Bologna process has contributed significantly in this direction and continues to have an ever more elaborate impact. Much still remains to be accomplished.

5.3 Entrants and institutions

Degree courses in universities are normally designed for ‘traditional’ students – young people just leaving school with good results in formal examinations such as ‘*le bac*’. In particular, entrants to SET courses are expected to be both recently and well- grounded in science subjects, especially mathematics. Indeed, in some national higher education systems, academic prowess in these subjects is the meritocratic criterion for competitive admission to élite institutions, regardless of its relevance to their later careers.

The professional SET workforce, however, is much too large to be drawn from this small segment of the population. What is more, there is no evidence that people who have not been well educated in such subjects at school, or who do not perform well in examinations in them, are inherently incompetent to become fully skilled researchers in due course. There is a lot of potential benefit from creating mechanisms for flexibility and repeated access where it is desirable.

In other words, a significant contribution to an expanded SET workforce, *at all levels of skill*, could come from the admission of **‘non-traditional entrants’** into the system, whether by

---

[57] European Commission: “The Role of the Universities in the Europe of Knowledge”, COM(2003) 58 final 05.02., p.5

making special provision for their needs in ‘standard’ universities, or by opening educational pathways for them into professional degree courses from other post-school institutions, such as colleges of further education. One of the strengths of tertiary education in the United States is the system of ‘state colleges’ and ‘community colleges’, where students mostly gain ‘technical’ SET training but from which many later transfer, without vast bureaucratic impediment, into regular university degree courses, sometimes going on to earn valuable postgraduate qualifications and associated research training.

Observe, however, that this function is not necessarily served by offering sub-standard ‘general’ courses of short duration in standard universities. Unless these are clearly designed for subsequent entry into particular professions, such as engineering or information technology, they are regarded by students – and their teachers – as even more unfocused than the regular SET curricula, and as clearly inferior in status to the mainstream of student achievement.

5.4 University curricula

The knowledge base required for professional SET employment, even in quite a specialised field, is so heterogeneous and undefined that there is no recipe for an ideal curriculum. Universities mainly teach in terms of the traditional scientific disciplines, concentrating on their respective theoretical paradigms. But in some fields this produces a very rigid curriculum, with a narrowly constrained succession of subjects, each a prerequisite to the next. It also tends to ignore vast areas of empirical knowledge, not only of ‘facts’ but of significant ‘phenomena’, about which a qualified researcher or technical practitioner ought to be well informed.

Curriculum reform is thus an arena of conflicting forces where the needs and capabilities of the average student are not necessarily paramount. From the perspective of this report, several features deserve particular attention:

- The **transition from school to university**. As if entry into a new institutional setting were not sufficiently confusing, students are typically plunged into novel seas of abstract thought and expected to swim for themselves. This may be a valuable training exercise in self-education and an invigorating experience for some future scholars, but it is often the initial cause of disaffection amongst the majority of students. It is also very poorly linked to modern working practices or research-based outcomes on the characteristics of effective learning environments.
- Students continually complain that SET curricula, especially in the physical sciences and their associated technologies, are too ‘**abstract**’ and ‘**difficult**’. For a few, this is a challenge which is even celebrated by many academics who have successfully passed the test and set it as their criterion of high academic achievement. But it is often simply a manifestation of academic pedantry, and not at all relevant or essential. Again, many students proceeding towards less-specialised SET careers are put off by this unnecessary tendency to overspecialise in their education.
- Although some SET students enter higher education with well-formed career intentions, this is not true of the majority. In any case, these intentions often change as they learn more, have problems with some subjects, and encounter novel ones. Thus, curricula need to be ‘**flexible**’ to allow for the complexity, diversity and changing priorities of student requirements and career aspirations, and to permit them to choose and adapt to unforeseen career paths.

- The wish to be more flexible encourages academics to develop '**interdisciplinary**' or '**multidisciplinary**' courses of study. This is highly desirable in principle, and is clearly essential in fields where new hybrid disciplines are emerging. But it has its pedagogic problems which should not be underestimated. Thus, it adds to the confusion and disaffection of students to be expected to take courses in several apparently unrelated disciplines without providing the intellectual facility for connecting and integrating their subject matter.
- First-degree curricula tend to be linearly organised and overtly reliant on a simplistic and epistemologically unsound pedagogic structure comprising two parts: theory and practice. In this context, the word theory is often used in ways that are in stark contradiction with the epistemology of the same discipline. Worse, this long-standing approach either ignores or assumes spontaneous development of an appreciation of the epistemological and reasoning aspects of each discipline as well as of the human and community side of any science. The same approach is also in sharp contradiction to long-standing findings from the learning sciences which characterise learning as intellectual growth requiring active engagement and social meaningful interaction with peers.
- Most SET employment, except in the mathematical sciences and a few very specialised research specialities, is concerned ultimately with the real world. This applies not only to 'engineering' and 'technology': the knowledge base of all modern 'science' is unforgivingly empirical. University curricula should therefore integrate the evidence base of their discipline with the more theoretical established knowledge framework; they should emphasise **evidence-based practices** and '**practical work**' to reassure students of the 'reality' of their new understanding and authentic internship work to help them bridge the gap between academic and applied work.
- In so far as many of these students will actually become professional 'researchers' and all will be employed in research-based organisations, it is helpful to give them some active experience of this type of activity. In fact, the inclusion of '**research projects**' in the university curriculum is also an effective antidote to student disaffection. From a practical pedagogic point of view, this is often very challenging, not least because it questions the separation between teaching and research which is now so characteristic of many universities. It may also involve active collaboration with industrial firms or other R&D organisations, including arrangements for 'sandwich courses' where students actually work for a period in such environments.

Needless to say, these can be no more than general suggestions for reform whose effective implementation must depend enormously on local circumstances. In some cases, they chime with local perceptions that the university system is in serious need of radical change: in other cases, they are likely to meet resistance from those who are quite satisfied with present conditions.

Indeed, it will surely be asserted that any such change must worsen the quality of the education and subsequent research training of the élite 'discoverers' and 'inventors' to whom so much attention is devoted. This assertion is unproven – probably unprovable. But it is disconfirmed by the example of the United States, where outstanding scientists and engineers eventually emerge out of a much less narrowly selective and academically specialised system of tertiary level institutions.

We would argue, rather, that the vast majority of students are being undermined and disaffected for the sake of this minority. This critique applies quite generally, right across

Europe, even to the most prestigious institutions. No increase in the number of university entrants to SET curricula is likely to produce an adequate expansion in the output of qualified personnel unless their educational experience within academia is reformed to conform to their real – and quite observable – career needs and priorities.

5.5 Graduands as career candidates

University undergraduate courses are sometimes allowed to drag on too long, but they do not last forever! Even students who enter without specific career aspirations eventually become concerned about what they should do when they graduate. One of the chronic complaints in student circles is the inadequacy of the information and personal counselling available to them about the professional careers for which they will, in due course, be qualified. Reliable, accessible, effective '**careers advice**' for graduands is now a vital instrument in the recruitment of a qualified SET workforce.

What graduands want to know, above all, is the actual professional value of the qualification they have been studying for. What employment opportunities does it open up for them, in what sort of organisations, in what range of specialities, and at what level of responsibility? Locally and nationally, this is usually governed as much by custom as by official regulation. But it varies enormously from country to country depending on the diversity in the economy as well as local organisational and management traditions.

One of the defining features of the European Research Area is mobility of workers, especially those with professional skills. So the '**standardisation of qualifications**' is of great importance in career development of individuals, and in the creation of an enlarged, integrated European SET workforce to meet international and national economic and societal needs. This effort will need to overcome and surpass the disparate peculiarities of individual national systems of higher education. In this direction, the Bologna process and the Tuning project have made important contributions in recent years.

The extent to which universities use the Bologna process as a mechanism for reforming the organisation and implementation of their educational programmes will significantly affect the extent to which Europe can respond to the challenge of the Barcelona strategy. In particular, universities will need to better respond to the needs of the knowledge society for active, critical and creative thinking to be an important attribute of all SET graduates just as they are an important aspect of all science disciplines. Universities will also need to reform their educational practices so that they serve as a mechanism for enculturation of all graduates into a diverse but committed community of practice that is relevant, challenging and creative in all its facets.

The educational system needs to be reformulated and tuned in order to safeguard the development of the core competencies which researchers and other knowledge workers need: critical thinking, reasoning strategies, collaborative problem-solving skills, project management and information-processing and restructuring, writing for a diverse audience, dealing with uncertainty, working with complexity and forward thinking are just some examples[58].

---

[58] Fontela, E. (2003), "Foresight, Higher Education and Human Resources", paper presented to the 'Foresight in the Enlarged European Research and Innovation Area' conference, Ioannina, May 14-15

There is mounting evidence which shows that life and career success are not as strongly correlated to performance in traditional educational goals as they are to attitudes, dispositions and other forms of achievement[59] [60]. Related work on ‘employability’[61], ‘practical intelligence’[62] or ‘emotional intelligence’[63] reveals similar findings. Universities should be encouraged to innovate in finding ways to integrate the different aspects of learning and to break away from the current singular emphasis on expertise. They should also be encouraged to take closer note of educational research and to take a concerted initiative to create measures that encourage institutional values for teaching. For example, Black and Wiliam’s[64] meta-analysis of the evidence on formative assessment concluded that it had a potential beneficial impact greater than almost any other educational innovation. Despite the sound research support for formative assessment, the findings are not well known. Nor is there much evidence of teachers in higher education acting upon them. A similar comment could be made about recommendations based on a massive meta-analysis of USA evidence about classroom instruction[65].

This line of thinking echoes the findings of research into employers’ accounts of what they want in the new graduates they hire. For instance, Brennan and colleagues[66] (2001) reported European employer interest in competencies including: initiative; working independently; working under pressure; oral communication skills; accuracy, attention to detail; time management; adaptability; working in a team; taking responsibility and making decisions; and planning, coordinating and organising. This is quite close to ideas developed by Sternberg and colleagues[67] about the significance in life and work of ‘practical intelligence’.

There is still much room for improvement in our understanding of the question: ‘What first-, second- and third-cycle processes support the development of these competencies?’ In asking this question we acknowledge the effect that the Bologna and Lisbon processes have had on thinking about the first and second cycles.

There has been some sophisticated work done in the USA on the learning that comes from first-cycle higher education programmes[68] [69]. It has shown that complex achievements, such as critical thinking, are associated with variations in learning environments over four years or more. It is complemented by work in schools that has drawn attention to the importance of learning sequences of teaching activities and learning tasks – to the ways in which learning

---

[59] Feinstein, L. (2000), “The Relative Economic Importance of Academic, Psychological and behavioural Attributes Developed in Childhood”, London: Centre for Economic Performance, London School of Economics

[60] Bowles, S., Gintis, H. and Osborne, M. (2001), “The determinants of earnings: a behavioral approach, *Journal of Economic Literature*, 39(4), pp. 1137-1176

[61] Knight, P. T. and Yorke, M. (2003b), “Learning, Curriculum and Employability in Higher Education”, London: Routledge

[62] Sternberg, R. J., Forsythe, G., Hedlund, J., Horvath, J., Wagner, R., Williams, W., Snook, S. and Grigorenko, E. (2000), “Practical Intelligence in Everyday Life”, Cambridge: Cambridge University Press

[63] Bar-on and Parker (2000), reference to be provided

[64] Black, P. and Wiliam, D. (1998), “Assessment and classroom learning, Assessment in Education”, 5(1), 7-74

[65] Marzano, R. J., Gaddy, B. B. and Dean, C. (2000), “What Works in Classroom Instruction”, Aurora, CO: Mid-continent Research for Education and Learning

[66] Reference to be provided

[67] Sternberg, R. J., Forsythe, G., Hedlund, J., Horvath, J., Wagner, R., Williams, W., Snook, S. and Grigorenko, E. (2000), “Practical Intelligence in Everyday Life”, Cambridge: Cambridge University Press

[68] Pascarella, E. T. and Terenzini, P. T. (1991), “How College Affects Students”, San Francisco: Jossey-Bass

[69] Astin, A. W. (1997), “Four Years that Matter: The college experience twenty years on”, paperback edition, San Francisco: Jossey-Bass

and teaching methods are blended over time[70]. There is a case for funding similar research in Europe.

There is a need for developing more systematic knowledge on effective higher education pedagogy. In part this is because subject areas have different concerns and because different learning goals require different pedagogy. Yet the lack of meta-analyses is striking and a reluctance to use the findings of those that have been done gives cause for concern. For example, informal and non-formal learning have been virtually ignored when it comes to thinking about pedagogy and curriculum. Some recent studies suggest that they can be more important than formal learning. An important point about these approaches is that they show that expertise and the learning that lead to it are individual achievements and group achievements. There is an increasing recognition that knowledge is distributed within work groups and communities of practice and therefore has a social as well as an individual dimension[71].

There are suggestions in what has been said of a need to reconsider the ways in which student learning is evaluated. There is a lot of agreement in Anglo-Saxon countries that the assessment of student learning is one of the most problematic areas in higher education. Some think it is the most urgent task. Arguably, unless progress can be made here, other initiatives will either fail (because they promote a complexity that defies fair and reliable assessment), or be undermined by assessment practices that favour simplicity and depend upon 'tame' and artificial tasks.

Curriculum design is another important issue that is often neglected. A worthwhile approach is suggested by Ganesan and colleagues[72] (2002). They argue in favour of thinking in terms of creating opportunities (or affordances) that support the types of learning we intend to happen. We should not assume that those intentions will be fulfilled immediately, measurably or, in some cases, at all. As Goodyear[73](p. 66) puts it:

> "*…we should recognize that we cannot influence directly the learner's cognitive activity ... the best we can do is help set up some organizational forms or structures that are likely to be conducive to the formation and well-being of convivial learning relationships. Learning communities may then emerge. Thirdly, we must recognize that the learner has freedom to reconfigure or customize their learn-place.*"

For such changes to happen, academic staff will need to be encouraged to take teaching seriously and to make it an object for serious reflection. Universities need to commit to evaluating and rewarding teaching excellence and to promoting innovative programme design. This all implies the development of a scholarship of teaching[74] [75] and explorations of

---

[70] Stigler, J. W. and Hiebert, J. (1999), "The Teaching Gap", New York: The Free Press

[71] Nonaka, I. and Takauchi, H. (1995), "The Knowledge-creating Company", New York: Oxford

[72] Ganesan, R., Edmonds, G. and Spector, M. (2002), "The changing nature of instructional design for networked learning", in C. Steeples and C. Jones (eds.) *Networked Learning: perspectives and issues*, London: Springer-Verlag, pp. 93-110

[73] Goodyear, P. (2002), "Psychological foundations for networked learning", in: C. Steeples and C. Jones (eds.) *Networked Learning: perspectives and issues*, London: Springer-Verlag, pp. 49-76

[74] Boyer, E. L. (1990), "Scholarship Reconsidered: Priorities of the professoriate", Princetown NJ: Carnegie Foundation for the Advancement of Learning

[75] Kreber, C. (ed.) (2001), "Revisiting Scholarship: identifying and implementing the scholarship of teaching", *New Directions in Teaching and Learning* 86, San Francisco: Jossey-Bass

ways of making that scholarship a major resource for the professional and educational development of those who teach in European universities. Fortunately, the Bologna process provides an opportunity to rethink the curriculum in first, second and third cycles.

5.6 Postgraduate education

For some, of course, academic success seems to indicate no serious alternative to entry into a postgraduate master's or doctoral programme. In this respect, the scientific disciplines in the SET cluster are different from most others, in that high-achieving graduates are presumed to have a strong preference for research careers and therefore immediately enter into research training. In many other disciplines, the majority of the best students tend either to enter directly into practitioner training for specific professions such as law, or else to seek employment outside academia, in business, government, the media, etc. This is the normal practice in Continental Europe, with its long undergraduate courses and limited 'American graduate school' tradition.

Nevertheless, even for those graduates intent on a career in scientific research, the choice between immediate employment and postgraduate study is not necessarily determined nowadays by relatively meritorious performance as an undergraduate. As we have seen, many industrial firms are recruiting high-quality science graduates directly into their research teams, and training them on the job. Conversely, the graduates of more modest academic performance, who are being accepted by universities into postgraduate courses at master's level, often prove entirely competent as research trainees and, in due course, go on to good PhDs.

Another factor in this choice is the very low level of '**postgraduate stipends**'. As we have noted, this is more a matter of custom than a market valuation of the labour involved or of its product. In the past, people accepted a few years of extreme poverty as a necessary personal sacrifice on the way to the satisfaction of an academic career. Nowadays, along with what they can see as the grinding labour and uncertain outcome of the training exercise itself, it undoubtedly influences many excellent graduates against taking this path.

For these, and other reasons, questions about the 'quality' of the graduates entering research training cannot be answered by reference to, for example, the proportion that have top grades. What is clear, however, is that postgraduate students cannot now be assumed to be academically self-sufficient and self-winding. It is not sufficient nor is it acceptable to put them in a research environment, suggest a project, occasionally discuss its progress with them, and eventually scrutinise their dissertation to determine whether it is of doctoral quality.

The whole process of research training now has to be much more carefully organised. Systematic, highly specialised courses of instruction are required to take the student up to the research front. Technical skills have to be imparted, including how to access the relevant SET literature and how to gain expertise in a range of established methodological techniques of the discipline. Regular sessions of supervision and mentoring are required, not only to help the student through the demanding work of doing real research, but also to ensure that this effort is being sustained. Furthermore, the whole process needs to be more closely tuned with future employment opportunities.

In addition, the future career of the doctoral candidate is no longer envisaged as quietly academic. News of what is going on in the laboratory needs to be brought to public awareness

– or may attract unwanted public attention – so training in media presentation is desirable. Many SET PhDs will be going into industry or into government service, where managerial and business skills will be required, so these should also be encouraged and nurtured.

Indeed, in many cases the ‘applied’ research undertaken in industry by teams of professional research scientists under the leadership and/or supervision of research managers and directors cannot be realistically differentiated from the ‘basic’ research undertaken in universities by teams of postgraduate students and postdoctoral assistants, under the leadership and/or supervision of members of the established academic staff. It is quite normal for postgraduate students to be employed as ‘contract workers’ on ‘strategic-basic’ or ‘strategic-applied’ projects performed in university laboratories at the expense of industrial firms. Conversely, some of the SET employees in industrial firms or public sector research organisations may be registered as PhD candidates in universities, presenting quite similar work, carried out ‘on the job’, as their dissertations.

In other words, the overall stock of skills and adaptive flexibility of the SET workforce is enhanced by no longer separating these different career paths at the first degree level: it is similarly enhanced by closer direct collaboration between universities and other research organisations in research training beyond this point. In effect, this goes beyond just ‘preparing postgraduate students for the job market’. It already involves them in some elements of this market, and exposes to them its full panorama of employment possibilities, before they cease to be students.

5.7 Research training

The established form of research training is primarily the PhD degree. In this section, we examine the current status of the PhD with particular emphasis on the aspects that may or may not be contributing to the quality of the outcomes of this training.

Every PhD-granting department in a university can largely set its own policies for recruitment, admission, and curriculum requirements[76]. Thus, graduate students’ experiences are strongly influenced by their departments’ cultures. Quantitative studies on graduate student attrition indicate that the department is the best unit of analysis when predicting graduate student completion rates (Berg and Ferber[77] 1983, Ott and Markewich 1985 as cited in Girves and Wemmerus 1988[78]). According to Girves and Wemmerus (p. 186):

> *“The department characteristics directly influence doctoral degree progress. The norms and expectations of the faculty vary by department. The nature of the department, including the attitudes of the faculty and the activities that they value and engage in determine, in part, the kind of experience that a graduate student has.”*

The PhD thesis in science is primarily an apprenticeship in research during which students spend large periods of time in a group sharing space and equipment with colleagues and

---

[76] Hirt, J. B., Muffo, J. A. (1998), “Graduate students: institutional climates and discipline cultures”, *New Directions for Institutional Research*, 25, pp. 17-33

[77] Berg, H. M., Ferber, M., A. (1983), “Men and women graduate students: who succeeds and why?”, *Journal of Higher Education*, 54, pp. 629-648

[78] Girves, J. E., Wemmerus, V. (1988), “Developing models of graduate students’ degree progress”, *Journal of Higher Education*, 59, pp. 163-189

research supervisor[79] [80]. Despite this, there are enormous variations in the extent to which a group is an institutional unit. Some research groups are extremely informal. Others have legal status and sometimes internal regulations. According to Conefrey (2000)[81], *"participating in a group is crucial to succeeding in science because it socializes novice scientists into what is valued by their group and by the larger community of scientists to which they aspire to belong"(p. 253).* Thus, it is necessary to examine the extent to which contextual factors, such as the working environment in the research lab, affect graduate student attrition, particularly of women. Golde (1998)[82] asserts that, *"to understand doctoral-student attrition, we must critically examine the role of discipline and programme in shaping student experiences"(p. 55).*

Because of the large number of hours spent in the research group, the social climate for students is often shaped by their relationship with colleagues and supervisor. There is extensive research that indicates that colleagues and supervisor are key agents in the socialisation of new graduate students into a discipline[83] [84]. According to Girves and Wemmerus[85], *"The frequency and quality of student/faculty interactions appear to be important predictors of retention for men, whereas both student/faculty and peer interactions are important predictors of retention for women"(1988: 164).*

Collegiality. While in some departments students remark that the 'emphasis is on co-operation/collaboration with other people', many other students comment that in their department 'each group does their own thing. There are no interdepartmental collaborations at all' or, as some students put it, 'You will be pretty much on your own'. It is also often the case that 'intra-lab politics make it difficult to work in a research group'.

In some research groups, the senior graduate students play an important role in the socialisation of incoming graduate students. This can often contribute to the socialisation of newcomers into a community of practice[86], but it can also serve to restrict access to membership in that community, if the person does not fit into the sometimes irrelevant normative characteristics of the membership at a particular instant in time (Lave and Wenger 1991 in Davis 1999).

Sandler (1986)[87] contends that issues related to the climate faced by graduate students are especially problematic because they occur at a time of transition between student and professional. During this stage of their education, students are being socialised into a chosen

---

[79] Widnall, S. E. (1988), "AAAS presidential lecture: voices from the pipeline", *Science*, 241, pp. 1740-1745

[80] Holloway, M. (1993), "A lab of her own", *Scientific American*, 269, pp. 94-103

[81] Conefrey, T. (2000), "Laboratory talk and women's retention rates in science", *Journal of Women and Minorities in Science and Engineering*, 6, pp. 251-264

[82] Golde, C. M. (1998), "Beginning graduate school: explaining first-year doctoral attrition", *New Directions for Higher Education*, 26, pp. 55-64

[83] Baird, L. L. (1992), "The stages of the Doctoral Career: Socialization and its Consequences", (Washington, DC: Educational Resources Information Center, ED 348 925)

[84] Lovitts, B. E. (1996), "Who is responsible for graduate student attrition – the individual or the institution? Toward an explanation of the persistently high rate of attrition", paper presented at the Annual Meeting of the American Educational Research Association, New York

[85] Girves, J. E., Wemmerus, V. (1988), "Developing models of graduate students' degree progress", *Journal of Higher Education*, 59, pp. 163-189

[86] Davis, K. S. (1999), "Why science? Women scientists and their pathways along the road less travelled", *Journal of Women and Minorities in Science and Engineering*, 5, pp. 129-153

[87] Sandler, B. R. (1986), "The campus climate revisited: chilly for women faculty, administrators and graduate students", Washington, DC, Association of American Colleges

field. This socialisation involves close and informal work relationships with peers and supervisors as well as competition for access to scarce resources. According to Sandler, at this level, peers often view each other as potential colleagues and competitors.

Student relationship with supervisor. According to Tinto (1993)[88], the graduate education process progresses in three stages: (1) transition to the programme, (2) acquisition of skills, and (3) conducting research. Graduate student persistence in the third stage is primarily the result of the student relationship with the supervisor (Tinto 1993). This assertion is supported by research on graduate student success (Jacks, et al. 1983[89], Girves and Wemmerus 1988, Hollenshead et al. 1994[90], Golde 1998, Davis 1999). Students often credit the collaborative atmosphere in their group to the supervisor's ability 'to treat all students equally and fairly'. Successful scientists, especially women, consistently report on the important role that their supervisors played in their careers (Jacks et al. 1983, Sonnert and Holton 1996[91], Davis 1999). Research on mentoring indicates that students who have a mentoring relationship with their supervisors feel professionally affirmed and are more productive after graduation (Heinrich 1991[92], Subotnik and Arnold 1995[93]).

Thus supervisors play a large role in the kind of work environment that exists in their laboratories, and in the department as a whole. Indeed, one might argue that supervisors are often the gatekeepers to their students' success, especially women's (Dresselhaus et al. 1995[94], OSEP 1996[95], Golde 1998, Davis 1999). Problems with supervisors are often the most cited reasons for leaving graduate programmes (Nerad and Miller, 1996[96]).

There are important differences from one context to another (often within the same department) in terms of the level of participation of graduate students in open debate about other people's projects or their involvement in the process of seeking funding. The extent to which a supervisor seeks the advice of students also varies enormously. The extent to which the PhD is gained in an environment where open dialogue is valued and encouraged has important consequences on the quality of the training. For a start, routines on how mistakes are handled and on how new ideas are evaluated internally have a strong impact on student confidence, on the socialisation process, and on student ability to function in an international professional community in the future.

---

[88] Tinto, V. (1993), "Leaving college: rethinking the causes and cures of student attrition" (2nd ed.), Chicago: University of Chicago Press

[89] Jacks, P., Chubin, D. E., Porter, A. L., Connolly, T. (1983), "The ABC's of ABD's: A study of incomplete doctorates", *Improving College and University Teaching*, 31, pp. 74-81

[90] Hollenshead, C., Younge, P. S., Wenzel, S. A. (1994), "Women graduate students in mathematics and physics: reflections on success", *Journal of Women and Minorities in Science and Engineering*, 1, pp. 63-88

[91] Sonnert, G., Holton, G. (1996), "Career patterns of women and men in the sciences", *American Scientist*, 84, pp. 63-71

[92] Heinrich, K. T. (1991), "Loving partnerships: dealing with sexual attraction and power in doctoral advisement relationships", *Journal of Higher Education*, 62, pp. 515-538

[93] Subotnik, R. F., Arnold, L. S. (1995), "Passing through the gates: career establishment of talented women scientists", *Roeper Review*, 18, pp. 55-61

[94] Dresselhaus, M., Franz, J., Clark, B. (1995), "Update on the chilly climate for women in physics", *The American Physical Society Committee on the Status of Women in Physics Gazette*, 14, pp. 4-9

[95] Office of Scientific and Engineering Personnel (1996), "The path to the PhD: Measuring graduate attrition in the Sciences and Humanities", ERIC ED 420 536 (Washington, DC: National Academy of Sciences)

[96] Nerad, M., Miller, D. S. (1996), "Increasing student retention in graduate and professional programs", *New Directions for Institutional Research*, 92, pp. 61-76

Competition and aggressiveness. Student comments often focus on the high work expectations that their supervisors are perceived to impose on the members of the research group. Students frequently mention the need for 'working hard' and for being 'self motivated'. According to some students, the high work demands lead to an atmosphere that is 'incredibly uptight and competitive, where you are constantly asked to prove yourself'. The prevailing attitude is: 'at all costs produce results and impress your supervisor'.

Research versus teaching. In many science departments the operative rationale is that students are being trained, primarily, for a research career in academia, similar to that of their supervisors. Teaching, according to the students, is not taught or valued and 'the way you are rewarded in the department is by not having to teach'. In fact, students speak of a 'deep divide between people who are teachers and those who are researchers'. Yet, students often enter graduate programmes partly because they are interested in teaching in higher education. However, the low status (and support) that teaching receives in departments restricts student options and sometimes acts as a source of disaffection.

Some departments have close ties to industry and it is acceptable (and expected) that many of the students will secure jobs in industry. In other cases, the lack of collaboration between the department and industry makes such options seem undesirable and not entirely feasible.

Methodological knowledge. Too often the PhD research project relies on application of a single methodological technique and the PhD programme is constrained within the collective expertise of a single department. The Bologna process and professional societies could potentially contribute significantly in creating new mechanisms for widening the doctoral candidate's experience with a range of methodological approaches. In particular, summer schools for doctoral candidates, in the fields where they do exist, demonstrate enormous potential in promoting European collaboration for providing the research trainee with a more wholesome experience of the research discipline and, at the same time, a period of intensive guidance by a range of practising researchers in the discipline.

5.8 Graduate training and work

While much praise is often given to the technical excellence of the graduate education systems, there has been increasing concern over the quality of the more general and potentially transferable skills of PhD scientists (Smith et al., 2002[97]). The quality of education in more general skills beyond technical knowledge is particularly relevant given the ubiquity of their use in the workplace. Skills such as oral presentation, writing reports, critical thinking, analysing data, designing research projects, working collaboratively in interdisciplinary contexts, human resource and financial management, as well as teaching and training are generally rated as much more important to the workplace in relation to the emphasis devoted to them during graduate training.

At work, most PhD holders report spending some of their time on R&D (Smith et al., 2002). However, relatively few scientists report often using knowledge of their dissertation and only about a third use knowledge of their speciality field. About three-quarters of the PhD holders who are in employment report using knowledge of their discipline while the rest report using experimental skills, computer skills or general knowledge of the science enterprise from their

---

[97] Smith, St. J., Pedersen-Gallegos, L., Riegle-Crumb, C (2002), "The training, careers and work of PhD physical scientists: not simply academic", *American Journal of Physics,* 70(11), pp. 1081-1092

graduate studies. Industrial employment tends to have the broadest distribution of knowledge use. At the same time, many of the more generic skills are reported to be equally important in all employment sectors. For example, even skills such as collaborative work in multidisciplinary contexts turn out to be important to the majority of PhD graduates in almost any employment sector.

It would appear from such findings that graduate training should not be viewed solely as a means of producing disciplinary specialists. PhD holders in the workplace are more accurately described as employees who use a range of general analytical and communication skills, albeit with substantial numbers who also use specialised disciplinary knowledge. Improving the training of PhD graduates in the general skills needed for both research and later careers should be an important goal. A general improvement in research skills would benefit the research system via improved performance from students and postgraduates. Better skilled graduates should also be more attractive on the job market, which may ultimately bolster the attraction and retention of graduate students.

6 Schooling for science, engineering and technology

Summary

Post-secondary schooling, especially at PhD level and beyond, plus training within science, engineering and technology establishments is specialised and caters for Europe's needs for a high-level workforce. The education provided is for mature students or adults and is able to build on their strong self-interest and motivation to raise their levels of expertise.

This contrasts greatly with education at the primary and secondary levels, most of which is compulsory across Europe. Here the education is given to develop the student, both individually and socially, to gain knowledge, skills and attitudes that relate to the cultural societies in which the students find themselves within the countries of Europe. The students are far from adults and schools have a responsibility to develop their mental, physical and emotional capabilities. In most schools this happens by dividing the school curriculum into subject areas so that the educational developments, which are expected to meet society's needs, are approached through the context of different subject areas.

Engineering is very rarely taught as a school subject. It is regarded as an aspect of technology, as are fields such as medicine and computer science (not computer education – this is promoting education through a context of a communication ability). Technology itself has a mixed development, sometimes mistaken for the promotion of computer skills – a communication skill and all too often mistaken for technical training, promoting psychomotor skills without the technological, theoretical underpinning. But science education (the teaching of science in schools) is universal and is often an umbrella for the teaching of science and technology and is frequently, especially after the ages of 12-14, subdivided into sub-branches such as biology, chemistry and physics.

All school education is driven by the aims put forward by society in the different countries and enacted by Ministries of Education. These aims are remarkably similar in wanting to promote intellectual, communicative, personal and physical, co-operative, social/moral skills and values. The students are being prepared as responsible citizens able to play a role within society, either through their individual prowess, or collectively in the decisions to be made, especially in an advancing scientific and technological world, or in a knowledge-based society. All subjects thus relate to these aims. They strive to develop the students not only in their intellectual capacity, but also to cater for their interests and talents and by developing lifelong learning skills such as 'learning to learn', social values such as 'respect for human rights', 'the need for sustainable development' and 'the promotion of tolerance and peace in the face of conflict'.

Unfortunately, science education has been inclined to isolate itself from the rest of education and has tended to be separated by society into its own subculture. There is a strong tendency to regard the teaching of science not as an area of educational development of the student, but solely for the pursuit of the subject matter. Science education is viewed as the learning of 'science knowledge', rather than 'education through a context of science'. There is thus a strong confusion between science on the one hand and science education (that which is promoted in schools) on the other. This is propagated by teachers and others and translated into teaching students to become 'little scientists'. The teachers thus stress the move away from the stated aims of education linked to the development of the student to become a

responsible member of society, of which developing their intellectual prowess is but one component.

Therefore, there is both an image and direction problem within primary and secondary education that needs to be addressed. While education needs to make students aware of career opportunities and develop their interests and skills to match their aspirations, this must be the province of education as a whole, not simply science education. And, of course, science education must guide students to develop the skills, interests and attributes to provide the support for students wishing to follow highly skilled technological or scientific careers. But this must be a component of education through science, not a separate, highly academic provision.

There is little doubt that, in developing students' interests and motivations towards science and technology and allowing them to become familiar with the fast-advancing developments in this area, it is essential that science education is on the curriculum from an early age. Science education should form a key part of the primary curriculum. But in recognising that students at this age are unable to cope with abstract ideas and tend to gain much from personal involvement activities, the 'hands-on' science education provided is easily accepted by students. Through this approach, it is easy to motivate and interest both boys and girls. This has been shown extensively by science centres across Europe, where the majority of visitors tend to be young children either coming as school groups or accompanied by their parents.

However, primary science, although very valuable and important, does not directly relate to careers. And the interests and motivation cultivated are not so easily sustained at the secondary-school level or, to recognise the hurdle more explicitly, beyond the onset of adolescence. It is the secondary school that is faced with the need to develop the intellectual capacity, to move to more abstract forms of thinking while coping with the students' own adolescent development and the change of interests that brings. For example, there is often a strong development of interests outside the school competing with the need for intellectual work inside the school. This is amplified by the difficulty in allowing education to keep pace with developments, both in terms of the society's changing needs and the attractiveness by which student distractions, or entertainment, are presented.

Science education suffers badly in this respect. Not only is it trying to cope with this image of 'becoming a scientist', but it is also fighting to relate to society. And yet it is being bound by an old-fashioned view that it must develop the 'fundamentals' which, all too often, are abstract, even microscopic, and far from the science ideas underpinning the technological advances within society which form the focus of debate and divide public opinion. It can be argued that science education in schools lives in a world of its own. It is unsophisticated because it is unable to compete with advances within the scientific fields. It is abstract because it is trying to put forward fundamental ideas, most of which were developed in the 19th century, without sufficient experimental, observational and interpretational background, without showing sufficient understanding of their implications, and without giving students the opportunity of a cumulative development of understanding and interest. It is heavily in danger of being excessively factual because of the explosion in scientific knowledge and the 'adding-on' of topics to an already excessive content base. And, to add to all this, the measures of assessment of student achievement has been largely confined to the regurgitation of information, with some hieroglyphics called formulae or equations thrown in. There has been little attempt to take a 'systems' view approach to the subject by appreciating patterns; conceptual and abstract topics such as energy or force are still heavily promoted in isolation.

No wonder society tries to reject science education as irrelevant and only useful for training to be ‘scientists’. No wonder students have a perception of science education as irrelevant and difficult. No wonder science teachers have little idea of society’s expectations and the directions they should take.

And finally, the poor image and perceived relevance of science education impacts on the career aspirations of students. While students see and may even interact with medical practitioners within society, and are familiar with the technology products that have been developed within society, there is little opportunity for students to experience careers in industry, in establishments not open to the public, or in areas where the career is pursued away from the public gaze. This problem is not easy to address. Making students aware of famous scientists, aware of the ways in which industry operates and how they strive for public support so that they can operate and enable society to prosper, are important. But they are no substitute for the ‘real thing’. Countries have developed programmes of work experience to try to bridge this gap, but there is no evidence that this encourages students towards careers in these directions. It seems the best we can do is to modernise the educational approach to science and technology education, make the school ‘education through the context of science’ more acceptable to society, and enhance student and guardian awareness of career opportunities that relate to the fields of science, engineering and technology. Unfortunately, we are unlikely to do that through the pursuit of international competitions such as the Olympiads, as these promote the ‘internationalism’ of science ideas and move science in schools away from the culture of society. The Olympiads, although offering prestige to both the winner and to national pride, do not play a role in bringing countries together within the European Union to focus on the issues of a knowledge-based society.

6.1 Situation and goals of school science teaching

Unlike learning languages, sports or music, school is the only place where students study (school) sciences and technology in a systematic way. They carry out (simplified) scientific investigations, they learn about the concepts and methods scientists use, and they should also be able to get an insight into the different fields in which scientific competence is needed and where scientific results or activities have an impact on either their personal lives or on society as a whole. Children meet science and technology in many realms of life. But it is only at school that they are exposed to science in an organised and explicit form. It is very likely that the first encounters with school science will make lasting impressions on their perception about what science is all about and on their attitudes towards science. While children may forget the actual content in the form of concepts, laws and theories, they are likely to remember the more personal and emotional part of their encounter with science. They may remember pleasure, joy, success, excitement – or a feeling of failure, boredom and of not understanding strange concepts and abstract ideas with no relevance to their daily lives. School science is also a focal point, where other sources of information and offers, e.g. from sciences centres or media, can be connected and discussed, thus linking school with other contexts. For many people, school education may even be the only time they get formal information and knowledge about the sciences and technology.

As regards the aim of supporting an increase in human resources for science, engineering and technology, two aspects have to be regarded as goals for school science teaching:

- School education should assure a good foundation of scientific literacy for all students. Looking at the world through ‘scientific glasses’ enriches the understanding and interaction with phenomena in nature and technology, it enables students (and therefore future adults) to take part in societal discussions and decision-making processes, and gives them an additional element from which to form interests and attitudes. These goals do not only refer to the students' personal and individual development: a culture that is critical, but open-minded for science and technology is the necessary basis for raising students' interests in scientific careers, as these choices are not only dependent on their own impression of competence, but are also influenced by parents, peers and the media, for example.

- Teaching and learning about and from school science must also raise an interest in taking scientific or science-related careers into account. Studies have shown that this is not an easy venture: whereas many people regard science as important for society and cultural development, they do not regard it as important for their own daily lives or for their own career perspectives[98]. Following this goal of raising interest in science careers, school education must therefore also provide students with an authentic view of science-related careers and a fundamental background of knowledge, competencies and attitudes about science that enables further learning and activities in these areas.

Consequently, school education has to solve the problem of building up interest and a basic expertise for *doing science* as a career, on the one hand, and stimulate interest and open-mindedness for *dealing with science-based questions and decisions* in daily life and in society on the other.

Nowadays, one problem with school science might be that curricula and teaching processes focus too much on future scientists. The international discussion about fostering aspects of scientific literacy in all students – as an addition rather than a replacement for preparation for future careers – is a step towards a more general education about and from science. Alongside this discussion, a comparatively significant effort has been undertaken to improve curricula and standards for science-related subjects, such as chemistry or physics. A lot of research has been carried out, for example to better understand students' conceptual understanding. Still, results of international comparative studies, such as TIMSS or PISA, were rather disappointing for many countries. One reason might be that knowledge from research has not really been implemented yet in curricula and teacher education.

Another worrying finding is the comparatively low interest among students in taking up science-related subjects at school, once they get the chance to choose subjects, which is the case in upper secondary education in many countries in Europe.

Several consequences might be derived from these concerns:

- curricula should consider and enable science education for all, as well as preparing future scientists; they should enhance knowledge, understanding and the development of competencies as well as curiosity, attitudes and an open-minded perception of science;

---

[98] Reference to be provided.

- the research- and experience-based knowledge about students learning processes and their development and support of interest has to be enlarged and implemented in curricula and teacher education;
- conditions for teaching and learning about and from science at school have to be optimised (e.g. equipment for carrying out experiments);
- teacher education and support will have to be analysed and improved to enable them to give students a more realistic insight into science-based careers and the meaning of science in society and their personal lives;
- methods of diagnosis and assessment have to be improved to give students and teachers a better understanding of their own competencies and of those necessary to deal with science;
- curricula structures and teacher training should enable teachers to deal with diversity, e.g. as regards differing interests between boys and girls, the social and cultural background of students, etc.;
- the influence of informal learning, e.g. through media, and of peer group attitudes will have to be analysed and taken into consideration at school; networks with science centres, science museums and even research labs, universities and industry should be built up to help improve school science (see chapter 7);

Hence, it is important to look beyond school science education as a medium of instruction and to study the picture of science (and of science-based technology) developed by both younger and older people. Through such studies, we can relate the outcomes – “What picture of science is developed by students, and by various groups of adults, such as teachers, scientists, and non-academics?” – to the inputs – “What picture is presented by curriculum material and by the media?” – in terms of the delivery process – “What do teaching and learning look like?”, “What scientific activities do students carry out?” and “What kinds of questions do they ask and work on?”. To improve science teaching and learning at school, we need to clarify its role during the lifespan of the individual student as well as that of an educated society in general. Closely related with these questions is the matter of teacher education and teacher support which must also be regarded as a major task to be dealt with.

The following sub-chapters will pick up these questions and discuss:

- what we know about students’ understanding, interests and attitudes, and what has been done or could be done to enlarge this knowledge base;
- which influencing factors must be considered to improve the situation; and
- what conclusions can be drawn to develop measures for short-term and long-term improvements.

Research results and ‘good-practise examples’ will be given to support statements and conclusions,. However, it is not possible to draw general conclusions and describe a simple overall picture because schooling and education conditions and structures are very diverse across the different European countries. It will therefore be an extremely important task for each country to adapt findings and conclusions to its own system and catalogue of measurements. The only thing that can be stated for all countries is that these measures must be coherent and feasible for all players, and form a long-term process which should be monitored and optimised to act and react to new situations, demands and conditions.

6.2 What do we know about learning processes and the development of understanding, competencies, interests and attitudes?

6.2.1 Assessing the quality of education in science-related subjects

Every European country has a universal system of education in which schooling in science is a major component. Traditionally, this has been concentrated in the ‘secondary’ phase, and not always available for all children therein. But the modern trend everywhere has been to extend the teaching of science down into the primary school, and to encourage it – even make it compulsory – throughout the lower secondary grades. Generally speaking, formal instruction in the natural sciences and mathematics is also available beyond that level for the great majority of school pupils, more or less according to their preferences and abilities. Needless to say, the provision of adequate facilities of this nature must be of the highest priority in any national policy, not only for expanding the SET workforce but also to increase the number of ‘scientifically literate people’ who can participate in decision-making processes on the basis of fundamental knowledge and understanding (which is not only helpful in daily life, but also for decisions in politics, law, etc.).

The actual *quality* of these facilities, as measured in student outcomes, is a more complicated matter, about which educational authorities, governments and the public in each country are naturally much concerned. Within any one system, relative examination data from year to year can provide some evidence of change, although the interpretation of these results is often disputed. But educational quality is almost impossible to define or determine ‘absolutely’ because it is so culture specific. The ‘universality’ of mathematical theorems and of the ‘laws’ of natural sciences does, however, enable meaningful comparative cross-national studies of educational performance in these fields – for example, the IEA/TIMSS studies and the OECD/PISA-studies. These studies have significant impacts on educational policies in most countries, and are described in some detail in the Appendices.

“Although the public focus in these programmes is on the 'league tables' of countries, sorted by mean performance, they also provide a rich source of data and analysis regarding several sides of the performance in reading, mathematical and scientific literacy of students, schools and countries. They also reveal factors that influence the development of these skills at home and at school, and examine their implications for policy development.”[99]

“The focus of TIMSS and PISA is on scholastic achievement measured against predetermined sets of criteria.”[100] From one point of view, these criteria are very relevant to the creation of a highly qualified SET workforce, since they either correspond closely to the conventional criteria for admission to the institutions and courses of study, which provide the advanced instruction and set the standards for these qualifications, or to what is regarded as being ‘scientifically literate’. Thus, a country that is high up these ‘league tables’ can be reassured that its school pupils will have been well prepared for the subsequent education. The studies do not, however, shed much light on what pupils find interesting or relevant, and ‘good results’ are no guarantee of positive attitudes or that the students are eager to pursue studies or careers in SET.

---

[99] Reference to be provided.

[100] Reference to be provided.

The same applies to success in international Olympiads, where highly selected young people compete publicly in solving very difficult mathematical and scientific problems. These serve to publicise science as a medium for high individual achievement and national esteem, but may have the side effect that the bulk of less-talented people feel even more convinced that this could never be a career for *them*. In effect, from another perspective, which we shall examine shortly, such indicators of educational quality may be quite misleading since they have little direct connection with the factors that motivate – and demotivate – young people with respect to such careers.

An even more subtle and more pertinent issue is whether certain core subjects in science education, namely mathematics and the physical sciences, are particularly 'hard'. As Roberts[101] puts it: "*given that a key determinant of whether a student chooses to continue with a particular subject is their current and expected future level of achievement (people naturally like to play to their strengths) then it is crucial to establish whether or not these subjects are indeed 'harder' than others. If mathematics and science are found to be harder (or thought to be harder) then this is likely to contribute to fewer pupils studying these subjects at higher levels.*"

Analysis of this issue is complicated by the fact that scholarly performance in these subjects is commonly taken to be an indicator of general intellectual ability. Solving problems that demand knowledge about theoretical concepts are also easy to examine and mark 'objectively' and thus are useful for meritocratic operations, such as the selection of candidates for admission to élite institutions. Thus, the widely held belief that there is a very strong correlation between 'being brainy', 'being good at maths', and 'likely to be good at research' may, to some extent, be an artefact of traditional practices rather than a firmly established fact of nature.

What we do know, as the example of computer skills shows, is that although young people do differ quite markedly in their ability to acquire certain types of specialised skills quickly, those who are not successful at this stage can often learn later to perform them adequately. Failure to pass difficult school examinations in mathematics and science is not a good reason for excluding students permanently from entry to a profession where, as a matter of fact, these particular skills are actually not required by everybody.

It is important, therefore, that these perceptions of mathematics and science as being unusually 'hard' are not needlessly developed early in education. In terms of examination policies, it is also desirable for pupils to have a broadly equal chance to achieve high grades in science and mathematics as they would have in other subjects. Without this, fewer pupils will choose to study science and mathematics at higher levels. Arguments about the merits of 'levelling up' or 'dumbing down' should be conducted with the understanding that although these traditional intellectual disciplines remain central to higher education for SET, they are neither the sufficient nor the necessary bodies of knowledge and skill needed for all professional SET work.

In other words, from the point of view of this report, the quality of science teaching is not only to be measured in terms of the performance of carefully selected pupils in these 'core' subjects. It refers to what can be achieved by all pupils during the years of compulsory

---

[101] Roberts report (2002): The report of Sir Gareth Roberts' Review: "SET for success: The supply of people with science, technology, engineering and mathematics skills", April 2002, p. 74

schooling as regards science and technology, by their attitudes towards further schooling in science subjects and participation in science-related subjects, and the progress made by the majority of those who do choose to continue these studies, whether in higher education or other modes of preparation for SET employment. This is the point where recruitment to the SET workforce may actually be decided. Therefore, these are vital factors in our study.

In the following paragraphs, certain key information about teaching and learning processes and outcomes, coming from research and experience, will be noted.

6.2.2 Development of understanding and competence

The widely accepted theoretical background to explain the development of understanding and competence is based on constructivist approaches: learning is regarded as an active process by the learner, building on his or her pre-knowledge, preconceptions, attitudes and motivation. The learning environment (including teacher and class) can stimulate and support this process, the influential aspects being, for example, the learning context or situation, its (personal) relevance, communication processes and social interaction, or the application and improvement of knowledge and concepts in different situations[102]. This theoretical background has led to certain demands concerning the design of learning environments, such as:

6.2.2.1 Interdisciplinary connections: relevance and different perspectives to understand decision-making processes

Science curricula and teaching processes are typically broken into ‘subjects’ and ‘disciplines’ that correspond to the academic classification of the sciences into research specialities. This is because the way to enter academic employment is by minutely specialised research in an already recognised field – so these are the fields that are taught to students. The disadvantage apparent from many observations is that students learn nothing of the diverse, technically fascinating, and socially invaluable interdisciplinary problem areas where much R&D is actually undertaken. Hence, movements towards improving science education do at least try to integrate interdisciplinary topics and approaches into new curricula, showing the interaction between different disciplines, different fields of careers, and between research, technology and society.

6.2.2.2 Context-based learning

Following the need for more authentic, therefore more interdisciplinary and connected approaches, the context in which learning takes place and scientific concepts and processes are embedded becomes more important in discussions about school education. The goal of enabling students to apply their concepts and competencies requires the highlighting of the connection between concept and context or situation. In some situations, daily-life concepts and terms are useful; in other contexts, only the scientific concept will be helpful in understanding or solving a problem. Misunderstanding the correct application of a concept or term cannot only cause mistakes and wrong answers – it also produces a feeling of

---

[102] Mandl, H., Gruber H. et al. (1997), Situiertes Lernen in multimedialen Lernumgebungen (2, überarbeitete Auflage), Information und Lernen mit Multimedia, Issing, L. J. and Klimsa, P., Weinheim, Psychologie Verlags Union: pp. 166-178
.

incompetence in science in general. Therefore, contextualisation and decontextualisation become important for a successful learning process, too.

6.2.2.3 *Adaptation to the learner*

There is a broad consensus today that all learning processes have to start with the pre-concepts, attitudes and interests of the learner, and that learning cannot be arranged and organised for every student in the same way at the same time. This constructivist idea of learning has led to many research studies and developmental work, aiming at the production of material and methods which look at student preconceptions and at different interests and competencies, and which allow a more successful handling of diversity, as guidance can be given to weaker students and more demanding tasks can be carried out by high achievers. The importance of preconceptions and theories also gives insight into the ‘nature of science’ and the historical development of scientific ideas. Several key ideas were not readily accepted such as, for example, that experiments could be interpreted in different ways according to the theoretical background researchers believed in (see, for example, the theories of phlogiston and oxygen).

Adaptation to the learner does not only refer to cognitive understanding. Different types of motivation or different cultural views about science are also very important for the stimulation and support of learning processes.

6.2.2.4 *Self-directed learning*

New approaches give greater possibilities for self-directed learning and for the application of many different competencies, not just the formulation of formulae and abstract laws. For example, competence in finding, analysing and presenting information – i.e. communication – becomes more and more important, not only for school science, but also for scientific and other careers. Of course, this also demands successful methods of support – what some have termed ‘scaffolding’. The necessity for a noticeable and comprehensible goal orientation for students is even more important in student-oriented learning situations.

In addition, various tasks take the diversity of interests into consideration: not all students have to do the same things, but instead can learn to work in teams even in school science classes, which can be one aspect of social embedding.

6.2.2.5 *Problem-based or inquiry-oriented approaches*

By combining different activities and focusing on open-ended tasks and self-directed learning, students are enabled to integrate and to develop different competencies and modes of creativity. To do so, students will have to be given the opportunity to undertake ‘research activities’ instead of just carrying out routine ‘cook-book experiments’, for example. This includes the development of questions, the formulation and testing of hypotheses based on existing knowledge and theories, and the analysis and presentation of results and conclusions – it means to prepare ‘minds-on’ and ‘hands-on’ activities.

6.2.2.6 *Cumulative learning*

The development of competence in conceptual understanding and application, or of skills in scientific methodologies, assumes educational structures that enable cumulative learning throughout the whole span of education. Therefore, a continuous and adjusted education in science is preferable as a starting point. This enables future citizens to inform themselves about societal or personal issues, as well as future scientists and engineers to carry out further studies. To arrange curricula in a way that is fostering cumulative learning, the most central concepts and processes of the different disciplines have to be defined and connected to different situations of application.

6.2.3 Development of interest, curiosity and attitudes

The development of and influences on students' motivation and interest can also be explained on the basis of well-accepted theories and empirical data, while influences on attitudes are much more diverse and more difficult to understand (see chapter 7). An existing and personal interest can be stimulated and activated by the learning situation, as well as the actual motivation for carrying out an activity. Again, some important factors can be mentioned that have been shown to influence motivation in empirical studies. These are the students' perception of autonomy ("Can I take some decisions myself?"), of their own competence ("Will I be successful, can I do this?") and of their being socially embedded within a (peer) group of people ("Will I get help? Will my friends admire or condemn what I can do?")[103]. The importance of the perception of competence and the learner's self-concept are pointed out in particular in different studies[104]. In addition, motivation depends on more school-related factors, such as the perceived relevance of the topic, the quality of instruction or the interest of the teacher[105].

During the individual development process, personal interests are generated, specified and established. Subject-specific studies on student interest have shown an interaction between the content, the context and the action that students carry out for the development of subject interest. Contexts dealing with the personal relevance of science and the importance of scientific knowledge in society have been shown to be more interesting than contexts dealing with historical development and careers, for example[106].

Note, moreover, that each individual develops specific interests during his or her developmental process. It is quite easy to motivate and interest students in primary school in almost everything, but this becomes much harder and sometimes impossible for older students. This narrowing or loss of interest holds for all subjects in general, not only for sciences. The natural sciences, as formal disciplines, have the disadvantage that they start rather late in the school curriculum – in some countries, students only start to learn chemistry at the age of 14 or even 16! Many other, competing interests will already have been developed in earlier years.

Nevertheless, if scientific and technological education is to meet the needs of the learners and be seen by them as relevant and meaningful, perhaps we should consider what the learners themselves find interesting and challenging. A number of research projects have tried to map their preferences. Two of these, SAS, Science And Scientists – and ROSE, the Relevance Of Science Education, are described briefly in the Appendix. Some results from SAS may disappoint the enthusiasts for more 'contextual curricula'.

---

[103] Deci and Ryan 1993: Deci, E. L., Kasser, T. et al. (1997), "Self-Determined Teaching: Opportunities and Obstacles. Teaching Well and Liking It. Motivating Faculty to Teach Effectively", Bess, J. L., Baltimore, The Johns´ Hopkins University Press: pp. 57-71

[104] reference to be provided:

[105] Prenzel, M., Kristen, A. et al. (1996), "Selbstbestimmt motiviertes und interessiertes Lernen in der kaufmännischen Erstausbildung", Zeitschrift für Berufs- und Wirtschaftspädagogik (Beiheft 13), pp. 108-127

[106] Gräber, W. (1992), "Untersuchungen zum Schülerinteresse an Chemie und Chemieunterricht", *Chemie in der Schule* 39 (7/8), pp. 270-273

- 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 fit well with stereotypical girls' and boys' interests – for example, boys are very much more interested than girls in learning about, for example, 'the car and how it works'.

- But the concern about making S&T more relevant by concentrating on what is 'concrete, near and familiar' is not necessarily meeting the interests of the children. It seems that both boys and girls are more interested in learning about the possibility of life in the universe, extinct dinosaurs, planets, earthquakes and volcanoes than about food processing or soaps and detergents!

- For the exponents of teaching about the nature of science, it is sobering thought that one of the least-favoured topics was 'famous scientists and their lives'. In effect, there is a danger of introducing another form of the academicism that most young people find so very 'boring'[107].

In addition to the diversity of types of interest, one has to differentiate between an interest in science in general, meaning an open-mindedness and an interest in science-based careers. As mentioned above, these two often go in diverse directions and not much has been discovered about fostering an interest in careers yet. Surely, views and beliefs about such careers play an important role in this field, for example as regards working conditions, salaries, career perspectives, acceptance in peer groups and others. This aspect will be described in chapter 7, but is also important for the design of school science.

6.2.4 The perception of science, science education at school and science-based careers

One important and overall problem concerning science education at school does not only start in the science classroom – it is the perception of the importance and personal relevance of school (science) education in general and the development of personal interests, influenced by school. The role of media is important in this area: students have the opportunity to find almost all the information they want on the web, very often designed in an interesting and summarised way. Two problems could arise from the growing importance of other sources of information: (a) school seems to be less important and less interesting for students, and (b) students pick up one-sided or even wrong information which is not always based on a critical scientific background. To avoid these problems, science teaching at school should clarify the special role of school education, make formal education in science more authentic and interesting, offer critical discussions about sources of information and the information itself, and link school science to these other sources and to later careers.

---

[107] Sjøberg, S., 2002, "Science And Scientists: The SAS-study Cross-cultural evidence and perspectives on pupils' interests, experiences and perceptions – Background, Development and Selected Results", *Acta Didactica,* No. 1 (2nd, revised, edition), Oslo, University of Oslo (available at http://folk.uio.no/sveinsj/)

Another general aspect that must be taken into consideration is the support that students will get during their education which, like other aspects, depends on parents' socio-economic background. In some countries such as Germany, this is one of the most important predictors for a student's achievements. Consequently, measures to avoid the loss of students due to insufficient support are also important.

On the whole, students' interests and achievements are the result of a complex system within school and between school and out-of-school contexts, and cannot be reduced to single factors only. This is the result of research studies that have tried to connect the outcomes of large-scale assessment studies like PISA[108] to factors regarding the whole school system (e.g. number of students in class, the assessment of teachers by students, or the superficial design of classroom activities and teaching scripts[109]. Correlation can be found, but it is not possible to identify one or more single factors as being *the* important predictor for outcomes of science classes in all countries. Therefore, actual research and intervention studies and programmes are (a) combining different systemic aspects (school system, teacher training, curricula, socio-economic aspects, etc.) or (b) looking in more detail at the interaction between teachers and students in different phases during the learning process.

6.3 Influencing factors

From the whole range of factors that influence students choice, interest and learning outcomes, three important aspects should be regarded more carefully on the following pages: structural conditions, curricula, and teacher training and support. These factors are not only influential but they can also be changed by governmental measures and opportunities. Examples of good-practice and several research studies build up a good starting point to develop, implement and monitor such measurements in the short and long term.

6.3.1 School systems – the structural factor

School systems are very diverse in different countries or even within a country when education is decentralised, for example in the federal states of Germany. It is hard to compare the achievement of different systems because of cultural traditions, characteristics of teacher education and, maybe, different roles that school education can play. However, large-scale assessment studies raise some questions about the structural and cultural characteristics of education in science:

- Countries in which students are not separated into different types of school in the early years seem to be more successful than those that differentiate early on, such as Germany. Is differentiation an aspect that fosters or hinders positive learning outcomes?
- How do students' achievements differ between those who were taught integrated sciences and those who studied different subjects? How are teachers trained in these subjects, which are either specific or integrated?
- Do more students choose careers in SET in those countries that have compulsory courses in science-related subjects in primary and/or secondary education?

---

[108] OECD 2001, "Knowledge and skills for Life – first results from PISA 2000", Paris, OECD (reports are available at http://www.pisa.oecd.org/)

[109] OECD: Bildung auf einen Blick, Indikatoren 2000, 2001, 2002

- What kind of support do different systems offer students with poor socio-economic backgrounds or language problems?
- How do different role models between teachers, parents, school and school administration – for example, as regards the freedom of curricula – influence achievement?
- How can the influence of other sources of information and training – formal or informal – be estimated?
- How can the influence of central and regular assessments and monitoring offers for students and schools be considered?

A lot of research is necessary to find out more about these questions, without disregarding possible cultural aspects, that can provoke good results within one system and poor results in another.

6.3.2 The curriculum factor

6.3.2.1 Problems and demands

Unfortunately, school curricula in the basic SET-related subjects have not progressed far from their traditional function as components of a ten-year process of preparing graduates for training in research. But the students who actually complete such a course comprise only a very small proportion of all students who take these subjects at secondary school. Little account is taken of the career and societal aspirations and circumstances of the remainder. School and university curricula in science are not just considered ‘hard’: they are widely viewed by these students as unattractively rigorous, formal and ‘academic’.

The image of science conveyed implicitly 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 concentrating 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. New words and ‘exotic’ concepts are introduced on every page of most textbooks, and yet many of the same old concepts and laws are also presented inexplicably year after year. Such curricula and textbooks encourage rote learning without deeper understanding. This is not only an unsatisfactory foundation for more advanced study, but it also has a more serious effect, i.e. that many pupils become bored and develop a lasting aversion to science.

Moreover, this textbook science is often criticised for its lack of *relevance* and deeper *meaning* for the learners and their daily lives. 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 stereotyped biographical anecdotes. Moreover, the implicit philosophy of textbook science is considered by most scholars to be a simplistic and outdated form of empiricism.

By contrast, many of the subjects with which the science curriculum has to compete for popularity, attention – and especially, student choice – have just those ‘human’ qualities that science seems to lack. Their presentation is less authoritarian, and it is easier to accommodate the opinions and feelings of the learners, which is seldom the case in school science as it is presently taught. This situation was captured well 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*” (15 August 1996).

With the current adult view of science dominated by a scientist image, science education tends to be poorly understood and little recognised as a potentially crucial player in making science in schools more relevant to students, more relevant to society, and having a useful and interesting role both in raising public understanding of science in modern society and in providing a confidence platform for handling future developments.

6.3.2.2 How can science curricula be made more ‘interesting’?

The literature trend is towards pointing out that science subjects are not taught for all students to become little scientists (emphasised in particular for general science courses), and the emphasis is on providing an education through a context of science. This trend translates into science education being more than the acquisition of scientific knowledge and skills, and science education incorporating additional educational attributes such as communication skills, co-operative skills and education values, in particular. In short, science education is being viewed as education through a context of science. This approach then begs the question whether any science context is appropriate or, as claimed by some (AAAS), there are grand science ideas that must be included.

The critique of the conventional science curricula – both at school and university – has produced calls for a change towards a more ‘authentic’, socially oriented approach. For example, STS (‘Science, Technology and Society’) and ‘context-based’ curricula, as well as courses designed to improve ‘scientific literacy’, take authentic situations and problems as the starting points for the development and application of scientific concepts and processes that have already been presented in the classroom. They thus provide insight into real scientific projects, display fields where science is carried out, and rehearse important discussions on social issues related to scientific knowledge.

These curricular innovations not only aim at the improvement of cognitive competencies, but they also take into consideration the motives and attitudes that come into play wherever scientific knowledge is sought or applied. From such science courses, students should develop an idea of the special mode that scientists use to explain and manipulate the world and of how scientific findings influence their own lives. Last but not least, they should offer students the possibility of trying to carry out their own scientific work, and thus to get an idea about what scientists do. Thus, learning science at school should enable all students to take part in discussions (as citizens), based on scientific knowledge, as well as acquiring more securely the basic understanding required to continue with science education and take up an SET career.

The enhancement of student interest and motivation in science and science-based careers is thus a major aim of context-based approaches. The theoretical reasoning for this is the highlighting of the personal and societal relevance of science. Relevance is one factor influencing motivation, next to teacher interest, quality of instruction, and – something most important according to almost all the theories on motivation – the perception and support of competence, autonomy and social embedding.

6.3.2.3 The necessity of ‘practical’ work

In some science education systems, ‘practical work’ – that is a regular sequence of school periods devoted to experimental, design, or other ‘hands-on’ technical exercises – has always been a major part of every SET-related curriculum. Quite apart from the connection with vocational careers, the theoretical arguments for this, in relation to the empirical and technological foundations of these subjects, are generally considered overwhelming, and most other countries are now trying to introduce ‘laboratory science’ into their schools.

Done well, practical work can both inspire and instruct pupils: done badly, it is a standard subject of complaint by uncomprehending, disaffected students and does not show any achievement apart from ‘fun’, when experiments are carried out as ‘hands-on’ – rather than ‘minds-on’ activities. SET laboratories and equipment are vital to pupils’ education in these subjects – both in directly educating pupils about areas of science and technology and in interesting them and enthusing them to study these subjects further.

At the primary level, where practical work is now seen to be particularly effective in influencing pupil attitudes towards science, competent teachers can often work with simple, even ‘home-made’ apparatus. At secondary level, not all schools are well enough equipped to offer lab activities for all students. Some work has been undertaken to replace expensive and complex apparatus by micro-scale or home-made experiments which can sometimes offer the added benefit of enabling motivating experimental homework as well. First results are very promising. Nevertheless, the expense of equipping schools with the necessary lab facilities and support by technicians, or reduced teaching hours, must not be spared if a country is to achieve the goal of a fully qualified and well-motivated SET workforce.

6.3.2.4 The necessity of adequate assessment

The enlargement of curricula towards more challenging and authentic scientific activities and towards achieving a greater relevance for everyone also requires changes in assessment strategies and instruments. If science no longer consists of theoretical knowledge about concepts and processes only, other competencies have to be assessed and their importance pointed out to students and parents. In addition, assessment has to be seen from at least three perspectives: (a) the traditional function is the evaluation of students’ achievement to put them on a certain ‘career track’ by giving marks and reports; (b) assessment should also be used as an instrument for diagnosis to give students and teachers permanent feedback about learning outcomes and difficulties, and therefore the need for support; (c) in recent years, international comparative and large-scale assessment studies have become more popular as they should enable broader knowledge about the conditions and influences on students’ understanding and competence. One effect of the latter is that much more effort was put into the development of models describing the development of competencies and into the development of useful tasks that can measure these steps of competence (PISA). Another effect is the enrichment and testing of different instruments to measure competencies, such as written texts, mapping strategies, portfolios and others.

6.3.3 Summary and recent trends in science curricula and pedagogy

The challenges facing science and technology education, outlined above, have been met in different ways. Many countries have introduced more or less radical reforms, including 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 (for development and implementation see chapter on teacher education and networks).

There seems to be something of general weakening of the traditional academic influence on the organisation of the school curriculum and its 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.

6.3.3.1 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. The general trend is that specialisation is postponed until the last few years of schooling.

6.3.3.2 Towards more subject integration

In the early years of schooling, science and technology are often integrated more or less 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.

6.3.3.3 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.

6.3.3.4 Stress on NOS: The Nature of Science

The ‘nature of science’ has become an important concern in the curriculum. This often means the 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 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.

6.3.3.5 Context becomes important

Increasing attention is being given to presenting science and technology in contexts that have both 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 very 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 need to be trained to work in this way.

6.3.3.6 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.

6.3.3.7 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 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.*

6.3.3.8 STS: Science, Technology and Society

STS has become an acronym for a whole international ‘movement’ within science and technology education[110]. 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.

---

[110] Solomon, J., Aikenhead, G., 1994, “STS Education – international perspectives on reform”, New York, Teachers College Press

6.3.3.9 *Attention to ethics and ability of judgement*

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.

6.3.3.10 *‘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) attempts 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.

6.3.3.11 *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, being 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, and statistical and graphical programs. In addition, modelling, visualisation and the simulation of processes are important. ICT is also used for taking a 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 their skills updated by means of suitable training programmes.

6.3.3.12 *In summary*

Many of these curricular and pedagogic developments are strongly resisted by influential individuals and élite institutions, usually in the name of ‘maintaining standards’. But closer inspection and practical trials seldom reveal any contradiction between this more open, humane and flexible approach to SET education and the successful transmission of scientific knowledge and skills to yet another cohort of pupils. On the contrary, in our view these reforms require sympathetic attention and further implementation if SET subjects are to maintain an honoured place as regards young people and their schooling.

6.3.4 Curriculum enhancement outside school, and career advice

Career advice is just one of the ways through which schools need to open themselves up much more to the world outside them. Quite generally – but in a great variety of specific ways – every opportunity should be taken to bring SET pupils into direct personal contact with researchers and research establishments, public and private. It should not be left to the media to provide images of the working spaces and working people inside laboratories, design workshops, hospitals, engineering test facilities, manufacturing plants, etc. More realistic pictures of scientific work and careers are those given by researchers and institutions themselves.

In essence, pupils and students perceive a visit to a science lab as being more interesting, the more authentic its presentation. Simple experiments aiming at a simple understanding are less striking than real research, even though the latter may induce more questions than answers on a simple level[111]. If young people are to get the feeling that these are good and appropriate places for them to work, they need to feel some familiarity with them. To achieve this, both sides, schools and SET employers, need to feel that this is partly their responsibility, and not leave it to 'the other side' to take the initiative.

Organised visits to science and discovery centres, science-related museums and other attractions can also help pupils to link the knowledge gained in the classroom to contemporary science issues, thereby helping to stimulate their interest. Governments have sought to enhance science and mathematics courses and promote them as enjoyable and interesting subjects through a variety of initiatives aimed at pupils, teachers, parents and other members of their community. The role of private organisations and businesses in enhancing pupils' learning experiences in science, technology, engineering, and mathematics is vital. Businesses and universities are well placed to help pupils relate the latest scientific breakthroughs to what they are currently learning[112].

In addition, in many countries there are numerous national schemes, awards, competitions, visits and other forms of resources and materials, sponsored by companies and other organisations, to support SET education in schools and motivate pupils in these fields. Such schemes can help pupils to make the link between the subjects studied in the classroom and the world around them.

Sports days or music and theatre presentations are very common for schools in most countries. The idea of presenting results from science classes might have another effect, too: they give parents a better idea of what scientific questions are, what scientific thinking and acting means, and how they can use scientific knowledge in their daily life or in discussions in society themselves. Results of such presentations quite often lead to statements such as "Why haven't we done things like that?", and might show other people, who no longer participate in formal learning of science, what can be learned from and about science at a non-expert level

---

[111] Euler et al., paper presented at the ESERA conference 2003

[112] For example, German projects offering interaction between centres, universities and schools, e.g.

- the governmental approach of 'science in dialogue',
- university projects that offer visits for students as well as teacher courses, e.g. the TeutoLab, the XLab or Chemol
- universities that offer regular visits for highly interested and high-achieving students, e.g. in Dortmund and Berlin

(see also PUSH initiatives). Thereby, school science can also have an impact on the development of popular ideas about sciences and on the influence parents and peers have on the choice of science-based careers for students later on.

However, from discussions with school representatives and organisers it is clear that the collective impact of these schemes is not as high as it should be. Teachers often have considerable difficulty in identifying and accessing the right scheme. Furthermore, they tend to overlap considerably, with the same pupils benefiting from each scheme rather than the schemes being more widely available to other pupils.

Critics point out that such special events need careful design if they are to have an influence on interest in studying science or starting out on a scientific career. Interest is strongly related to personal factors such as self-concept, the perception of competence, and the perception of personal relevance. Activities like experimental days are thus much more successful when integrated into the school science curriculum, where they can be used to raise questions or to apply and discuss knowledge already learned at school.

Visits to research institutions and industry should also take care not only to present their most advanced and fancy technical equipment, but also to promote their institution as an interesting place to work, socially, culturally and environmentally. Stress on the purely technical aspects may in fact increase the image of the SET sector as being ‘nerdy’ and not a socially and personally attractive environment.

6.3.4.1 Career advice

All commentators on SET-related schooling agree that one of the problems with attracting and retaining people in SET is poor or non-existent careers advice. This is particularly pertinent for the 11-14 age groups as well as for the 16-18 age groups, where important choices are being made, and when SET is seen as ‘uncool’ and peer pressure is all important. Students have no insight into what scientists can do to contribute to the future of society. Most staff (often teachers) involved in careers advice has no SET background, and some may even share the stereotypical views on these subjects and related careers.

Context-based approaches should enable students to develop a more realistic picture of science and science careers, to understand the importance and useful applications of daily life and of scientific concepts in different situations, and to try some methods of scientific inquiry and explanation which might be a base for further interest and studies. But this is no substitute for providing them with precise information about the variety of opportunities that will be open to them and the types of career they might be able to follow, whether as technicians, professional engineers or research scientists.

Young people are notoriously ignorant of such matters. For example, they are told through the media that the highest paid jobs are not scientific jobs. But they are not told that job insecurity and unemployment are much lower for those leaving higher education with SET degrees than for those with qualifications in the arts and humanities. This can be observed in almost all European countries[113].

---

[113] European Commission: Third European Report on Science and Technology Indicators 2003, p. 208

In practice, the need for well-informed and sympathetic career advice is not confined to students leaving school, college or university. It is also required throughout their formal education, as they find themselves having to choose between courses of study leading to different career paths. But pupils tend not to make the connection between ‘going on with science’ – which they largely do because they are ‘keen on the subject’ – and embarking on an SET career. Should one continue with mathematics, for example, even though it is not one’s ‘best’ subject, in order to keep open the possibility of eventually becoming a professional engineer? Will a decision to take a ‘vocational’ course close the door to real scientific research – or might it not be precisely the way to enter that desirable world as a technical trainee?

On the other hand, as the Roberts report points out, “*some pupils are being put off studying SET subjects because they are led to believe that ‘you only study science to become a scientist’ or that ‘if you study science you can only follow a career as a scientist’. […] A study funded by the Wellcome Trust in the UK found that ‘There was little recognition that a science qualification may be as valuable a generic qualification as one in mathematics or English.’ This is a serious issue, particularly given the increasing breadth of opportunity for scientists and engineers, for example in ICT-related jobs.”*[114]

Other countries in the EU suffer from some of the weaknesses noted by Roberts[115] in the facilities for career advice in UK schools. These include:

- *Teachers often do not see themselves as a source of information or advice about careers in science and technology – not feeling able to keep up with careers information, and instead leaving it to the careers advisers with whom they had very little direct interaction. The highly content-driven science curriculum gave no time for wider-ranging discussion about current science issues and careers.*
- *There is insufficient coordination between advisers and science departments on activities designed to enhance pupils’ awareness of opportunities in science-related areas, such as parents’ evenings, conventions/industry days, and joint training days for careers advisers and teachers.*
- *The majority of the careers advisers surveyed were graduates with a humanities or social science background. Only one in ten had science degrees, with none possessing physical science backgrounds. (Such non-scientists and engineers will need more support from teachers, businesses and others in advising on science and engineering careers, whereas in fact the study found both a lack of systematic training and of the updating of occupational information available to advisers.)*
- One of the difficulties in providing this sort of information is that it does not flow automatically into the institutional environment of SET education. This is one of the areas where there is an overwhelming need for educational institutions at every level to establish active partnerships with all the various firms, research institutes, government laboratories etc. that actually employ qualified SET workers. But here again there are problems of detail that need to be addressed. Thus, according to the Roberts report[116], *schools often find it hard to secure work experience places in science and engineering because of insurance and health and safety issues, or a local shortage of science-based employers.*

---

[114] Roberts, p. 79
[115] Roberts, p. 79
[116] Roberts, p. 79

- In a word: one of the most economical ways for EU countries to upgrade the quality of their SET workforce would be to spend the relatively small sums required to expand and greatly improve the facilities for career advice to all school, college and university students in these subjects.

6.3.4.2 Vocational education in SET

In talking about science education in *schools*, we are necessarily including a number of institutions – let us call them *colleges* – which actually perform a considerable proportion of the formal teaching at the immediate pre-university level. But the primary purpose of *further education* (as it is officially called in the UK) is to educate and/or train young people who have just finished compulsory schooling, as well as more mature students, for or in a wide range of practical vocations.

Needless to say, all high-tech enterprises depend entirely on a good supply, in both quality and quantity, of ‘technicians’. As we have noted, it is extremely important for people employed in this type of work to be able to gain the higher qualifications required to undertake ‘professional’ responsibilities. Thus, one of the major functions of these colleges is to provide courses opening up the paths into higher education, together with instruction for a whole range of ‘vocational’ qualifications, some of which are quite rightly held to be at ‘degree’ level.

Nevertheless, the distinguishing feature of all ‘vocational’ studies, whether or not they count as ‘higher’ education, is their direct attachment to *practice*. That certainly need not mean that they are free of ‘theory’. In all serious SET practice, whether or not it constitutes active ‘research’, an elementary understanding of the overarching paradigms is an essential component of ‘technical’ skill. But any suggestion of ‘academicism’ is fatal to the attention of students who are taking these courses for strictly vocational reasons.

Vocational education in SET subjects is thus a serious challenge to teachers and their institutions. In effect, instead of treating technical practice as the lowly logical outcome of high-level scientific and technological theory, they have to present good practice itself as a dominant mode of action that makes use of various forms of theorising – classification, pattern recognition, model formulation, mathematical analysis, etc. In other words, ‘college’ science should not just be a ‘watered-down’ version of pre-university or degree science, with the more difficult, abstract bits omitted or oversimplified. It requires a different, carefully thought out and well-tested approach, both in the design of the curriculum and in the way it is taught.

This is an ideal which is often in the minds of teachers in these institutions, although it is not given nearly enough attention amongst educationalists or institutional authorities. In the real world, moreover, pupils are increasingly likely to take a mix of academic and vocational qualifications. In many countries, there is no sharp boundary between academic courses and vocational courses, while in others it is becoming increasingly blurred. Indeed, the expansion of the SET workforce increasingly requires the recruitment of young people through the vocational route into more highly qualified employment. Thus, more emphasis on and experience of technical and technological practice t the pre-university levels in schools may be more valuable than forcing colleges to compete directly in the academic market place.

6.3.5 Teacher supply, support and training

A lot of research results are known, many papers have been written and a lot of material has been produced to improve teaching and learning processes in sciences. Unfortunately, many of these ideas have not found their way into schools and classrooms. Several reasons could be behind that: first of all, teachers do not read these papers, maybe because of the language used, maybe because of traditions. In addition, the results presented might not be what teachers are looking for. The research often describes problems and unsatisfactory results, but it does not always name practical measures that might be helpful to overcome such problems. Also, teaching processes are as personal as learning processes. One may therefore question the possibility of searching for general rules and theories for teaching and learning. Nevertheless, certain statements can be raised to develop promising measurements that might lead to an improvement in science teaching and learning. One necessary condition is the recruitment of professionalised teachers, while another is the offer of support and networks for a continuing developmental process.

In some countries, policy measures react to a shortfall of teachers in certain subjects by either engaging teachers who were trained in other subjects or employing people from careers in related disciplines who never received any educational or pedagogical training. Why can such reactions cause problems? The teaching profession is depending on the integration of subject or content knowledge – which does not only include knowledge about concepts but also about processes, careers, impacts on society, etc. – and a deep understanding of students’ abilities, learning processes, interests, etc. The term “pedagogical content knowledge” points out this necessary integration[117]. In addition to that, the teaching profession affords a high amount of flexibility and creativity: a teaching situation can only be partly planned and prepared because of students’ reactions and other impacts[118]. Policies, demands and goals also change over time, and teachers must be able to react and adapt their teaching to these influences as well. Last but not least, as in every other profession, theoretical and empirical knowledge from research about teaching and learning should be implemented continuously to ensure a high quality of education.

Further on, teachers can make a huge difference to their pupils’ enthusiasm for a subject, as well as directly influencing their pupils’ achievements in it. Teachers’ subject and pedagogical content knowledge, alongside their teaching style, are vital factors, but it is often their enthusiasm that captures a pupil’s interest and motivates them to study a subject. The recruitment, training, employment conditions, continued professional development and career retention of well-qualified school and college teachers in the whole range of SET-related subjects are crucial for the maintenance and expansion of the SET workforce.

In some countries of the EU, the need for highly qualified and enthusiastic teachers does not seem to present any particular problems. In many others, however, there are some quite specific concerns which need high priority attention.

6.3.5.1 Shortfall in well-trained and graduate teachers

For years now, many countries have experienced severe difficulties in filling teacher training places – and teaching jobs – in SET-related subjects.

---

[117] Reference to be provided

[118] Bromme, R. (1992), "Der Lehrer als Experte. Zur Psychologie professionellen Wissens", Bern, Huber

Alongside shortfalls in numbers, the data also suggest clear differences in the pool of recruits attracted to teaching different subjects. Teaching is not attracting the same pool of talent in SET disciplines as it is in many other subjects. There is no necessary link between university degree performance and ability as a teacher – there are, for example, highly qualified scientists and mathematicians who have poor communication skills and who would find it difficult to teach their subject well.

A reflection of the unrewarding environment and more attractive careers outside of teaching is the higher attrition rate for mathematics and science teachers, exceeding not only that of other occupations, but also of other teachers in other disciplines.

In dealing with teacher shortages, it is also important to consider the small but growing number of mature entrants to teaching and those who return to the teaching profession. Given the relatively small number of graduates in mathematics and the physical sciences, late entrants to the teaching profession in these subjects are likely to become increasingly important. However, it will be necessary to build up structures for good training. Simply recruiting people from other careers into teaching might not achieve high teaching standards! There is concern about political activities that enable doctors from scientific disciplines to enter teaching without any further qualification.

Another major effect of teacher shortages in certain subjects is that their places are being filled by qualified teachers trained in other disciplines – for example, biology science graduates have to teach physics. Very broad science courses that are not differentiated into the traditional specialities also encourage the phenomenon of science teachers teaching outside their area of expertise, since schools often prefer this to losing continuity in the classroom. In some countries, most science degrees tend to be in a single science (e.g. chemistry), and yet graduate teachers are often expected to teach right across the sciences. As a consequence, around two-thirds of the classes will be taken by a teacher who does not have a degree in the subject being taught.

There are also concerns over the level of initial training that teachers receive in the sciences. This is particularly important in primary schools, where very few teachers have a strong scientific background. In most countries, teachers in primary schools generally teach an almost full range of subjects to their classes in order to build as strong a relationship as possible with the pupils. The subject knowledge that primary school teachers require to teach the elements of the SET cluster of disciplines does not require them to have an academic background in any of these subjects. Nevertheless, to teach science well, primary school teachers must be able to explain potentially complex scientific principles in an interesting and simple way to their pupils, and relate these principles to their personal experiences and to salient contemporary issues. Given that very few of these teachers have a degree in a science- or engineering-related subject, it is important for teachers to have access to such topics in their initial training and in ongoing science-related continuing professional development.

Once again, these weaknesses show up in the physical sciences. It seems that primary school teachers are sometimes unable to explain very elementary physical phenomena correctly, or to stretch their pupils adequately in these more mathematical subjects. They have less confidence teaching the ‘physical processes’ and ‘experimental investigation’ strands of science, than they have teaching the ‘life and living processes’ strand. This might have consequential effects on the numbers of students taking these sciences up through secondary school and beyond.

6.3.5.2 How can SET teaching be made more attractive?

The problem of adequate recruitment is partly due to the increasing demand for SET graduates from other sectors combined with static or falling numbers of graduates in a number of science and engineering disciplines. There are a great many different factors that are said to make teaching unattractive. These include: the low public status of the teaching profession in some countries, heavy workloads, poor pupil behaviour in some school districts, an unsupportive working environment, frustration with low student interest, poor career prospects, and others. Although these factors vary between European countries, they certainly deserve attention.

But the most significant stumbling block to recruiting more science and mathematics teachers in most countries is salary. Some governments have therefore taken steps to target financial rewards to teachers of subjects in which there are teacher shortages – for example, through the introduction of ‘golden hellos’[119] – and the flexibility for schools to target additional allowances on particular recruitment and retention problems. These have had an effect, although serious shortages and recruitment difficulties remain and are damaging pupils’ attainment.

6.3.5.3 Continuing professional development, CPD

As in all other SET professions, science teachers require, and benefit enormously from continuing professional development (CPD). This is not just because the content of their curricula are always changing, or that they need to maintain contact with new trends in pedagogy and educational theory. It is also because the factors and circumstances discussed above often mean that they have to start teaching subjects in which they are far from expert.

For example, CPD is vital in improving primary and lower secondary science teachers’ understanding of, and ability to teach, all areas of science – particularly those areas related to the contemporary issues that are discussed in society and the media and that are most likely to capture pupils’ interest. At the other extreme, CPD also allows science teachers to stay in touch with the latest developments in their specialist subjects, which can be an important retention mechanism. Teachers with knowledge of what is going on in the SET world are better able to interest science and engineering students in these subjects and enthuse them to study the subject at a higher level.

The opportunity to obtain further formal qualifications through CPD is also of more than personal benefit. A teacher’s level of confidence and understanding, which has a significant influence on the achievements of their pupils, is strongly correlated with the highest level of qualification that that teacher has in the subject.

CPD is thus an important element of the professional package that teachers should expect from their employer. Conversely, employers should see it as a valuable recruitment and retention mechanism as well as an effective means of improving teaching performance. All in all, it has very considerable leverage in raising the standards of the whole SET workforce.

---

[119] Roberts, p. 120

It is worrying, therefore, that in some European countries few teachers develop their knowledge and competence through CPD, and that little personal reward follows if they do so. As a matter of policy, teachers should be offered CPD, and given generous salary, workload and promotion incentives to attend CPD courses. Such courses should cover the whole range of aspects dealing with knowledge about content, students and learning situations, and competencies to plan and reflect teaching or to assess and diagnose learning processes and outcomes. To make these courses more realistic, they should also involve other actors in the SET world, such as research organisations in the private and public sectors. Thus, industry should be actively encouraged to involve itself in continuing teacher education, through mentoring and ambassador schemes as well as master classes in practical work for teachers.

6.3.5.4 Science education as a professionalised discipline

Today, the field of science education research and development is an academic discipline in its own right. Like the field of mathematics education, it has a history that started long before World War II. Prominent scientists have played a major role in the establishment and development of these fields. Science education bears the signs of being a profession: there are chairs in science education in most universities (and in Germany there are some 250 full professors in science education), academic degrees are awarded in this field, there are several international journals, there are centres for research and development (like IPN, Institut für die Pedagogik der Naturwissenschaften, in Germany) and there are research foundations with special programmes to promote research and development in science education (such as NSF, the National Science Foundation, in the US). Further details on this are provided in the Appendix.

Similarly, science teachers have established national as well as international organisations and interest groups. Some of these are also briefly described in the Appendix.

The important thing in this context is to note that the field of SET education and research is well organised, has well-functioning networks, journals, conferences for communication, etc. Great care should be taken to make the maximum use of these existing networks when concrete activities in this field are suggested by the EU or other actors! Otherwise, the effect of actions may, in fact, be detrimental.

6.3.5.5 The need for the networks

A sad fact of teaching is that once the classroom door is closed, teachers are on their own under ‘normal’ conditions. They are in charge of the teaching direction, the choice of materials, the pace of learning, the atmosphere created, and the learning emphasis. Developing these skills requires expertise and experience and is aided by interactions with other teachers, especially in the same subject areas. To initiate and to support co-operation between teachers or even between teachers and researchers in education or fields of SET, several programmes have been started and achieved[120].

---

[120] There are approaches, for example, in Germany, such as SINUS (maths and sciences), QuiSS (all subjects), BLK21 (sustainable development), ChiK (chemistry): Jäger, M., Reese, M. et al. (2003), “Evaluation des Modellversuchsprogramms Qualitätsverbesserung in Schule und Schulsystemen”, *Psychologie in Erziehung und Unter-richt* (50): pp. 86-97

Also, science teacher associations have grown up from the need for teachers to exchange experiences and to be made aware of new ideas and developments. The science teacher association comprises a network for teachers, together with other interested bodies, e.g. teacher educators, curriculum developers, examination personnel, although its success is very dependent on the vision of a willing few to help the many. Nevertheless, such an association represents the best example of ‘teachers helping teachers’ and developments driven ‘by teachers, for teachers’. It is a peer group professional support mechanism and contrasts with a top-down model of pushing teachers towards implementing ‘ready-cooked programmes’ in which they can act more like technicians than translators. Consequently, attempts to change the curriculum by providing new syllabuses have often failed: teachers tended to adapt the new syllabus to their former way of teaching rather than the other way round.

While a national science teacher association forms a network within the country and through its activities, dissemination mechanisms, and the dynamism of its leaders can reach out to teachers willing to be part of the network, the national association is limited in its outreach in other countries. Here, the science teacher association relies on its links to other national science teacher associations for wider networking. Some examples of networks are briefly described in the Appendix.

6.3.6 Summary: A need for different strategies to implement new approaches and integrate continuing professional development

Successful programmes aiming at improving science teaching and supporting and professionalising teachers have always integrated teachers into processes of change. They offer frameworks which enable teachers to develop guidelines and activities for a specific situation, for a specific time frame, with specific students (acting as professionals). They also offer support through networks and instruments to help them improve their teaching. And last but not least, they should deliver information about how to improve science teaching in general and not only for those taking part in special programmes.

Some key factors seem to be important for the successful implementation of programmes[121]:

- Systemic approaches. The implementation of new programmes not only depends on the teachers involved, but on a good fit between structures in the school system, structures in the school, and the people involved.

- Co-operative approaches. Results from research on teaching and learning have barely found their way into school practice. There is a strong need for closer co-operation or communication between researchers and practitioners about planning, conducting, interpreting and applying research and experiences to improve school practice.

- Process-oriented approaches. Education goals are not stable, they have to change following the requirements of natural and social structures, and they should also

---

Parchmann, I., Gräsel, C. et al. (2002), "Chemistry in Context - Curriculum Development and Evaluation Strategies", UYSEG/IPN International Symposium "Evaluation of Curriculum Innovations", York
Prenzel, M. and Ostermeier, C. (2002), "What Can We Learn from Different Forms of Evaluation: Experiences from a Quality Development Program in Science and Mathematics Instruction", UYSEG/IPN International Symposium "Evaluation of Curriculum Innovations", York

[121] Gräsel et al., 2004, in press

continuously integrate knowledge and findings from research. Therefore, teacher training should not be aiming at the delivery of ‘the’ teacher-proof curriculum. Rather, it should allow teachers to develop *their* way of teaching, to have a background in a variety of teaching, learning and diagnostic tools, and to adapt this knowledge and their competencies to new situations. Teacher-training courses should also build up structures that enable and support lifelong learning right from the beginning.

6.3.6.1 Pre-service teacher training: the basis for further learning and development

The basis for a continuous implementation of new knowledge and approaches of (subject-specific) teaching and learning is the education of teachers to start with. After all, it is the teacher who (a) presents science to the students and (b) prepares and moderates their learning processes. Therefore, teacher education plays a crucial part in the effectiveness and outcomes of science teaching and the recruitment of young scientists.

A proper treatment of teacher education falls beyond the scope of this report, but some points that are examined in several research studies and education programmes should be mentioned here.

6.3.6.2 Teachers´ beliefs about learning and science

Teachers' beliefs about the nature of science and about teaching and learning influence their teaching, and therefore their students. As studies have shown, the orientation towards more constructivist beliefs about learning have effects on the design and the use of different, more open and student-centred tasks, which again have effects on students’ achievement[122]. Instruments and methods of scaffolding have to be met during teacher education, of course.

The results concerning teachers’ beliefs about the nature of science are different: some studies report effects while others say that a clear understanding of the nature of science was less important to explain successful teaching than other factors[123]. But next to the influence on the design of teaching and learning environments, an authentic picture of what scientists do and how the scientific mode to explain and analyse the world looks, will be important to allow students to develop a more authentic picture about sciences, too. So one should ask the question about where teachers actually encounter authentic sciences: during their university education, they hardly ever work in or observe real science projects – their theses (if a thesis is part of their teacher training!) might be the first and only time when they get involved in scientific research. Later on, they might listen to talks at conferences or read articles, but once again they are not involved in authentic science projects. One approach to improve this situation would be an integration of projects during the teachers' pre-service or in-service training, realised through networks of co-operation between teacher education and research institutes or researchers at university. For example, future teachers could be involved in research projects as some kind of ‘rapporteur’, as the teacher’s role later on will not be to carry out scientific research, but to know about it, to understand how and why it is done, and to present and explain it to non-scientists. In any case, one should make teaching material for science courses more authentic through the co-operation of teachers and researchers.

---

[122] Stern & Staub: reference to be provided

[123] Lederman, 1992, “Students’ and Teachers’ Conceptions of the Nature of Science: A Review of the Research”, *Journal of Research in Science Teaching* 29/4, pp. 331-359

6.3.6.3 Identified problems of teaching and learning and aspects of good teaching

Research has identified several areas of competencies that seem to cause particular difficulties for teachers. These are, for example, an overemphasis on the structure of a subject discipline during their own training, instead of on the learning process, the handling of open and complex learning situations (with less teacher direction), the handling of student diversity, or the capability of diagnosis and feedback[124]. Indeed, all the latter aspects are seldom the focus during teacher education in most countries, maybe because they cannot be taught in theory but have to be experienced, analysed and reflected in practice.

"What does good teaching look like?" This might be the hardest question to answer! One indicator is the actual time students spend learning and working on meaningful tasks[125]. Certainly, there is not just one good way of teaching to engage students in this way. It is a very old wisdom that a *variety of teaching and learning methods* is important for a successful learning process. For some students and some situations, a clear teacher-centred way of teaching with a highly organised structure can be the most effective way of teaching. On the other hand, active engagement ('minds-on') is necessary for a successful learning process. Video analyses have indicated that high achieving countries show very different pictures of teaching and learning on the superficial level, e.g. concerning the organisation of classroom work (group work and class work). Therefore, these superficial analyses can probably not be used to explain good teaching and less successful teaching. Much *deeper insight* into communication processes, into the interaction between students and teachers, into the handling of questions, mistakes, etc. is necessary. Further research projects are needed to find out more details about such conditions and effects and about successful measurements towards improving teaching and teacher education in such a way.

Some 'typical' elements of science teaching, such as the use of experiments, have become objects of research investigations again. Against some expectations, the development and use of many different student experiments have not shown the results of enhancing student motivation and understanding by itself[126]. Therefore, actual studies are looking at the *integration of experiments into the course work*, at the role of the students in the processes of planning, carrying out and interpreting experiments, or at the aims teachers are trying to reach in doing experimental work. The clarity of goal-orientation for students is one important factor in a successful learning process, not only for experimental work but also in teacher education where the focus must be shifted from just carrying out experiments towards discussions about students' possible ideas of interpretation, preconceptions influencing the analyses, and good tasks to combine hands-on and minds-on activities.

Another neglected aspect in teacher education is the *classroom climate* factor and the teacher-student relationship which appears to be extremely important for the enhancement of interest and the assessment of a classroom situation by students.

Last but not least, the formulation and *clarification of teaching goals and methods of diagnosis and feedback* become even more important with the introduction of *standards, benchmarks* and *competency models* that have recently become a prime concern at both national and international levels. Standards do not only regard the content side of a subject,

---

[124] Reference to be provided
[125] Reference to be provided
[126] Reference to be provided

but describe different competencies related to subject matter, such as content standards, skills, attitudes, communication, and others. One reason for formulating standards, competencies and benchmarks is the need for regular monitoring as a basis for improving school education. Another reason might be the orientation of constructivist approaches, which are looking at student concepts, ideas and achievements more than at the input given by a teacher. (This does not mean that this input is not important any more, but to understand learning processes, the connection between input, process and outcome has to be analysed.) The emphasis on students' outcomes and learning processes demands a high competence of diagnosis and reflection, both for the teacher and the learner. Unfortunately, the results from research often show that different teachers assess the same work of students differently. Therefore, better tools and methods to support diagnosis and feedback are needed and have to be implemented and evaluated into school practice and teacher education.

6.4 Ways forward and conclusions

The preceding paragraphs make it clear that the challenges facing contemporary science and technology education are multifaceted. 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 regarding 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 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 permit, or even stimulate, early selection and specialisation 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 towards, 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. It is precisely because they are so deeply embedded that 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 ongoing evaluation that is informed by evidence and careful analysis.

6.4.1 Conclusions

Even though the question of improving school education about and from science, technology and engineering is a very complex and highly situational and cultural issue, some general conclusions can be drawn from experiences and research:

- Overall, a network of different measurements is necessary, integrating school systems, teacher education, the integration of school education and other formal and informal learning opportunities, and others. These measurements must be coherent and feasible for all actors, and they must focus on short-term necessities as well as long-term developmental processes. They must be accompanied by monitoring systems rather than offer a continuous and flexible optimisation process.
- Measurements cannot be implemented successfully without the active involvement of participants, primarily teachers, and they cannot be realised individually. Therefore, networks between teachers and other experts and stakeholders have to be set up to work together on improving science teaching.
- More effort has to be put into the development and successful implementation of curricula for teacher education and for school teaching that give more authentic pictures about science and science-related careers, enable more student-oriented learning, the combination of building up expertise for future scientists and a fundamental scientific literacy for all, and that consider the development of interest, open-mindedness, attitudes and competence next to an understanding of basic scientific concepts and processes.
- Understanding and interest in science must be developed continuously. Breaks between primary and secondary education or even within secondary education make it much harder to keep up interest and understanding.
- More detailed research on systemic compounds of school education and into the interaction between parents, schools, teachers and students to create successful learning processes and the development of interest. Describe ‘good practice schools’ which are integrated in their community, which have built networks, and where the interaction between all groups of people takes place in a successful way.
- Teacher education should also work out ways to integrate research- and experience- based knowledge about teaching and learning, as well as to integrate insight into authentic research and careers in SET. Building up networks could be a way to realise these demands.
- More acknowledgement and credit should be given for special engagement or achievement, for both students and teachers, as extra incentives.

6.4.2 Comparative achievement studies and statistics on SET education

There are many excellent sources of up-to-date international information and analysis on education. Here are a few:

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 printed statistical reports that are also available via the website 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.

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, although the acronym TIMSS will have a somewhat different meaning (e.g., T for ‘Trends’ instead of ‘Third’). The data collection took place early in 2003.

The OECD has a large education sector, and it publishes an important annual report *Education at a Glance* (i.e. OECD 2001*b*). This, as well as other reports, including underlying statistical annexes, are available online at http://www.oecd.org/

The OECD has recently developed its own set of studies on 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 to assess how far students who are approaching the end of compulsory education (around the age of 15) have acquired some of the knowledge and skills that are essential for full participation in society. The first report (OECD 2000*a*) presents evidence from the first round of data collection on 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 future. Reports, background material and statistical data are available at http://www.pisa.oecd.org/

The second round of PISA data collection took place in early 2003 and results were expected to be published by the end of that year. In 2003, the focus was on mathematics; in 2006 it will be on science.

6.4.3 Other comparative studies in S&T education

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 13-year-old pupils. 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[127], but here are some of results that relate to interesting topics in the science curriculum (one of the seven 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 is 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. However, the real surprise is that the actual difference is so extreme. Take learning about 'the car and how it works', for example: in Norway, 76% of boys and 33% of girls are interested. Japan is even more extreme, although the actual numbers are much smaller: 36% of boys, and only 6% of girls are interested! The results for car-producing Sweden may cause some concern: 83% of boys and only 32% of 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. For example:

Most popular among girls and boys in most countries are the following topics:

- The possibility of life beyond earth
- Computers, PCs, 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 least popular subjects (for girls and boys) in most (mainly rich) countries:

- How to improve the harvest in gardens and farms
- How plants grow and what they need

---

[127] Sjøberg, S., 2002, "Science And Scientists: The SAS-study Cross-cultural evidence and perspectives on pupils'' interests, experiences and perceptions – Background, Development and Selected Results", *Acta Didactica,* No. 1 (2nd, revised, edition), Oslo, University of Oslo. (Available at http://folk.uio.no/sveinsj/)
Sjøberg, S., 2000, "Interesting all children in the 'science for all' curriculum". In: Millar, R., Leach, J. and Osborne J. (eds.), *Improving Science Education – the contribution of research,* Buckingham, Open University Press

- 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 can see that concerns about making 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.

A more systematic follow-up study to the SAS project has been developed under the acronym 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 compulsory schooling in many countries, and before streaming usually takes place. Researchers and research institutions from about 40 countries are taking part in ROSE. Data collection will be finished early in 2004 – a description of the project is given at http://folk.uio.no/sveinsj/

6.4.4 Associations and networks in S&T education

Below are a small number of various associations and networks within this field. Some organise teachers, while others organise teacher trainers and science education researchers. Organisations for professional scientists also have special groups with education in their discipline as their main focus. Examples of such are the International Unions for Chemistry (IUPAC), Physics (IUPAP) and Biology (IUBS).

In many countries, there are national associations and organisations for *science teachers* and teacher trainers. Some of these, like ASE – the Association for Science Education – in the UK, have existed for about 100 years. Most European countries have similar associations, often with annual conferences, journals, development projects, etc.

ICASE, the International Council of Associations for Science Education, was established in 1973 to extend and improve science education for children and young people throughout the world. Today, ICASE is a huge network of science education associations, institutions, foundations and companies, facilitating communication and co-operation at the regional and international level. ICASE is working with more than 150 member organisations in over 60 countries to support science. On several occasions it has operated closely with UNESCO, for instance since 1993 when *Project 2000+, developing scientific and technological literacy for all,* was launched by ICASE and UNESCO.

ESERA, the European Science Education Research Association, organises researchers (most often, but not always, involved in teacher training) in science education. (Corresponding associations exist in the USA, NARST and in Australia, ASERA). ESERA has biannual conferences with about 400 participants, and also runs summer schools for doctoral students in science education. Smaller associations exist in many countries and regions, and in Europe http://www.physik.uni-dortmund.de/didaktik/esera/about.htm

IOSTE, the International Organisation for Science and Technology Education, was established during the cold war (1979) to promote contact and dialogue across political and ideological borders. A key concern was that education in science and technology (S&T) is a vital part of the general education of people in all countries. The vision is that education in S&T should prepare young people as informed, critical and active citizens. IOSTE has arranged ten international and many regional symposia since its inception in 1979. The 2004 international symposium will be hosted in Poland, which will open up the possibility of integrating new partners from the emerging Member States : http://ioste11.umcs.lublin.pl/

STEDE, Science Teacher Education Development in Europe, has been a thematic network in the European Commission's Erasmus programme since January 2001. It links together 119 researchers from 24 European countries involved in the area of science teacher education. The focus of the STEDE thematic network is to develop the effective use of curriculum and didactic research and development in the development of science and technology teachers, particularly with respect to education in scientific literacy : http://www.biol.ucl.ac.be/STEDE/

National resource centres for SET education exist in many countries. They are often funded and partly 'governed' by MOEs – for example, Sweden has four centres divided by disciplines, Norway has one for mathematics and one for science, and Germany has IPN which is probably the largest in Europe.

National initiatives for promotion and recruitment in S&T studies and careers exist in many countries (*Ciência Viva* in Portugal, *NOT-project* in Sweden, *LUMA* in Finland, etc.).

7 The cultural context of recruitment for research careers

Summary

Europe has a long history going back to antiquity and beyond. The past shed light on the processes involved in the interactions between science and society. Those were long term but they played an important role in the transformation of European society from an agriculturally oriented one to an industrial society. The so-called Industrial Revolution depended on the diffusion of knowledge and demonstrated the importance of cultural background in the development of key innovations through useful knowledge. Besides purely economical parameters, innovation is boosted by an intellectual and cultural context. However, the rational basis of the science invented in Europe (F.Bacon, R.Descartes), and its goal to tame Nature, met strong resistance early in European history in that more attention was requested for nature and for human feelings. This is a characteristic of European culture that has few or no equivalents in the Americas and Asia. It deserves special attention when innovations are at stake. This problem is important today as, under this dual cultural view, the image of science and technology may be a confused one for young people and may hinder career choices.

Strategies for science popularisation have been in use since the 17th century, and remain very active today. They are usually supported by governments, public institutions, research organisations, scientists, museums, and science centres using a variety of pedagogical forms. The actions of the main actors are reviewed. They can be divided into two approaches, classical public understanding of science (PUS) trying to bring to a general public and to young people more information and knowledge into science matters, and a networking approach based on the idea that extended dialogue and direct contact between citizens and scientists is necessary in order to promote scientific culture in society and to help citizens to acquire a better understanding of controversial issues related to science and technology.

Media are a very important intermediate between science and people – 60% say that they get their scientific information from television. However, the media (TV, radio, movies, newspapers, magazines, novels, comics, etc.) have their own rules and use science and technology mainly as a source for narratives which attract people through conventional storytelling and spectacular images or situations. Nevertheless, they make science familiar and this is the main point of entry for the introduction of science into society through culture, as shown yet again by history.

However, a review of national and European programmes and initiatives in this area shows that there is an urgent need for a comprehensive European strategy for scientific culture across Europe.

Some data from public opinion surveys about science and technology and knowledge issues are summarised in the annex below.

Certain economists doubt that actions to improve science popularisation and even science teaching at primary and secondary levels are really helpful in increasing recruitment into science careers. They believe that the most important point, on which efforts should be concentrated in Europe, is at university level. We do not agree with these views that, in our opinion, disregard the social and cultural context of scientific development in democratic societies and the need to reinforce and widen the social consitutency able to support scientific and technological development, namely the very wish to study science and to pursue science and technology careers.

7.1 Introduction

In this chapter we will investigate the cultural and social factors which may influence the supply of human resources for science and technology in Europe. History illuminates many of the key points in the relationship between science and society in Europe, which goes back to antiquity. We will make many references to the past. In a recent book[128], an economist, Joel Mokyr, underlined the importance of intellectual factors in the history of the European "miracle", the Industrial Revolution in the 18th century, and subsequent progress:

"*The intellectual origin of the Industrial Revolution and European economic growth have been underrated by economic historians and yet are too important to be left to the historians of science and technology.*"

He shows "*the complex ways in which social and cultural factors determine technological outcomes*" using several examples from the past. Social and cultural factors are embedded in public opinion influences, educational trends, propaganda and the style of small "élites" which try to promote new ideas, institutions which may be efficient actors (such as learned societies, publishers, academies, museums, etc.), the media, and the mood of politicians. Technological outcomes depend on the capacity of research and industry to produce a new technology economically, but also on its acceptability by people and political authorities, and on the recruitment of a human workforce with the necessary capabilities and willingness.

Increasing human resources in Europe for science and technology is an action which may depend on the social historical and philosophical context in present-day Europe. Some of the factors at work are briefly summarised below as they are part of a complex web of influences which act on each individual and may influence the choice of careers.

At the time of the Enlightenment, "*a cultural change took place in which a growing number of people were influenced by Bacon's idea about the function of human knowledge*". The scientific method is to be supported by experimentation, assuming that "Nature" is intelligible. Fundamental science is at the heart of research and organises knowledge. But science is also, in the interest of the state, at the service of commercial and manufacturing interests. This is a good description of "a knowledge-based economy". "*In the seventeenth century, the practice of science became increasingly permeated by the Baconian motive of material progress and constant improvement, attained by the accumulation of knowledge.*" The distinction between 'pure knowledge' and 'useful knowledge' oriented towards applications is already very clear in the mind of people, especially the politicians who began to support research and scientists, as suggested by Bacon. For instance, Louis XIVth's powerful ministers, Colbert then Louvois, insisted that the newly created Académie des Sciences worked on matters which could "increase the Greatness of the Monarchy" in agriculture, commerce, navigation, military warfare ... One of their civil servants suggested drawing a firm distinction between "*la recherche utile*" and "*la recherche curieuse*"[129].

---

[128] Joel Mokyr, "The Gifts of Athena", Princeton University Press, 2002; we would like to thank Dr Luc Soete for bringing this book to our attention

[129] Académie des Sciences: "Histoire et mémoire de l'Académie des Sciences", Lavoisier Tec et Doc, Paris, 1996, pp. 4-13

Diderot, in “La Grande Encyclopédie”, glorified Bacon (who had been very popular in France since the translation of his work[130] in 1624) and insisted on opening all knowledge to all people, including the secrets of the manufacturing arts.

Because of its obvious historical and economical impact, the diffusion of knowledge is traditionally supported in Europe by the scientific community, the educators, governments, and by every social, intellectual, commercial, military or political unit which has an interest either in the diffusion process itself or in the benefits to be expected from the knowledge accumulated by people, especially the workforce.

However, the values of the Enlightenment were contested right from the beginning. There was a revolt against the Baconian and Cartesian programmes of *taming* Nature. Figures such as Jean-Jacques Rousseau objected to the development of technologies and even to extending education to too many people, whereas the “philosophy of Nature” was developed on the wings of the romantic movement (Friedrich Schelling) and created another cultural reference in Europe for which Nature, feelings, intuition … are at least as important as reason, logic and science. The persistence of those opposite views for more than two centuries is an important and unique characteristic of European culture. It influences the image of science in society and has political consequences.

This divide is clearly visible today, and resistance to the Baconian view has been going on for two centuries (see chapter VI of Mokyr’s book entitled “The political economy of knowledge: innovation and resistance in economic history”). As the present difficulties with youngsters’ interest in science may be linked to the influence of that type of ‘resistance’ in the public sphere, it is important to investigate the trends today.

Popularisation of science has been supported by governments in Europe, from the 17th century to the present day, in the form of gardens, museums, schools, exhibitions, etc. as part of forging a climate of confidence in the efficiency of knowledge in society and in response to curiosity. In the second part of the 20th century this trend was exasperated by competition between nations, especially after the *Sputnik* event in 1957. New methods to improve science education were tested. Science centres for children flourished. But in the 1980s, a new wave of resistance appeared with the development of the ‘green’ movements and the influence of a postmodern philosophy sceptical about science and technology being seen as politically based “constructions”. Science popularisation was slow to evolve from a classical “deficit model” (Public Understanding of Science), in which people are fed information, to a “dialogue model” on problems involving science, technology and societal issues, especially the development of new technologies. For PUS, ones hope that telling more about science will increase sympathy towards science (which is obviously good in this framework), whereas the dialogue, or participation, model tries to expose, and eventually overcome, fears and doubts through a debate and requests for the participation of scientists and other professionals. Governments are now shifting from PUS to the more open dialogue system, as seen by the orientation taken by some very large science museums in Europe and the organisation of many events where “people meet science”. The growing importance of the entertainment industry (TV, movies, best sellers) in shaping public feelings is also an important component as many science-based plots are used and can generate emotional reactions. Young people in particular are ‘targeted’ by many initiatives, private or public, in order to increase their

---

[130] Francis Bacon: The Two Books of Francis Bacon of the Proficiency and Advancement of Learning Divine and Human , to the King, London, 1605

awareness of the importance and utility of science and technology with some expectations that such an offer will influence their choice of career.

Some economists are very dubious about the efficiency of those policies for the *recruitment* of a workforce for R&D. Two OECD experts recently wrote under the title[131] "Cultivating, attracting and retaining the high-skilled":

"*At the heart of becoming an innovation-led economy is the need to have people who innovate. Policies in this area tend to focus on increasing the scientific and technical skills of the public at large through primary and secondary schools, vocational training facilities and training. This is an important component but its impact is diffuse, will only be felt in the long term and is more likely to result in a better public appreciation and acceptance of science and new technologies than it will have in their direct development. In this sense, policies that are directed towards increasing the overall S&T knowledge of the population rather than improving high-level S&T skills are less well suited to creating the next generation of innovations than to facilitating the diffusion of innovations created elsewhere. This is the paradox represented by the US: even though its capability to innovate is high, its primary and secondary school system has long been considered inferior to that in many OECD countries (NCEE, 1983). It is the country's tertiary-level education that makes the difference.*"

On the contrary, the connection between scientific culture and "direct development" is more or less the thesis in the book by Mokyr. The OECD point of view in that area also ignores the problems generated, in a democracy, by public opinion moods and the actions of "resistance" from vested interests which can have a devastating impact on emerging technologies. They add:

"*More important for cultivating highly skilled S&T workers, however, are factors linked to academic and research opportunities. The key policy implication is the need to create world-class universities that act as a beacon for students around the world who want to study with the best and be taught by those at the forefront of the field. Doing so requires an examination of the role of universities in the community and their societal mission, especially in Europe where most universities are public and where student admissions are less selective than in the US.*"

If the reader is convinced by the OECD arguments he/she should turn back to chapter V.

7.2 Science and opinion

Ever since Plato[132], philosophers have debated whether or not 'opinion' necessarily stood in opposition to 'true knowledge'. Very early in European history, it also became apparent that the social situation of the scientist depends on opinion about the interest of research. The oft-told story of Thales looking up at the stars and falling into a well is typical. In literary works, from classical Greek drama to modern novels, criticism of the scientist as a person 'out of this world' is extended, quite generally, to the pursuit of knowledge and to all expressions of curiosity. The fate of technological innovators such as Icarus or Prometheus, doomed by a curse, is another signal. Greek philosophy had a contempt for craftsmen which is still echoed by important 20th century philosophers such as Heidegger.

---

[131] Jerry Sheehan and Andrew Wyckoff: "Targeting R&D: Economic and Policy Implications of Increasing R&D Spending", STI Working Papers 2003/8, OECD, Paris, 2003, p. 33

[132] Plato: "Opinion is nothing but the power which makes possible to judge on appearance", *Republic*, V, 479d-e

Plato vigorously defended knowledge and learned people (whose strangeness is in fact wisdom) against a ‘common sense’ which places more value on pleasure, power, property, family, money, etc. Nevertheless, ‘eggheads’ like Thales are still stock characters in movies, TV series, and comic books. For example, scientists provided some of the first ridiculous characters for the very first movies, such as Méliès’ *Travel to the Moon*.

The images of scientists as weird characters in some TV shows may influence children at a very early age and affect later choices of careers[133]. It is known that bright students in some classes “*may be faced with ridiculous stereotypes*” and, as a consequence, “*they could reject science and engineering as potential careers*”. There are TV shows, however, such as the current Cousteau series, which give youngsters a vision of scientists as dedicated people. In fact, despite some media inclination to make fun of scientists, they are held in high esteem by most people (see the annex to this chapter).

Opinion making is very important as its results may directly influence members of the political community in their choices and decisions. As Plato emphasised, opinion has *power*. Today, the stakes are higher since they involve major scientific issues, for instance in biotechnology. It is difficult to decide such issues solely on the basis of scientific information, particularly when most people lack the necessary knowledge to grasp the technical features of the problem. In any case, people have the right to voice their views, even though these are built on appearances such as the apparent trustworthiness of the spokespersons for one or other side. This perfectly proper democratic principle is growing in strength and cannot be neglected. As a consequence, scientists and industry have to build new communication channels to explain what they are doing and convince people that these are the right things to do. Although Plato dismissed opinion he remarks[134] that a science cannot develop if it is spurned by the city. A science needs public support to be efficient and, as Bacon noted, this implies providing those who work on it with very good social and material conditions because, if not, research will stay in the hands of “weak people”.

7.3 The use of opinion by scientists

Science is part of society because, as the historical events reported below illustrate, it is promoted by scientists themselves, and this is still going on today through all sorts of channels. Modern science appeared in Europe at the beginning of the 17th century. The scientists were not very numerous, their discussions were difficult to follow without a proper education, but from the start they had what would be called today “a politics of communication” with two targets: the affluent public and the political authorities. They wrote books using controversy as a narrative trick (Galileo). Scientists have to make their work known to attract support especially among the upper social classes and state authorities. In France, it is the state itself which organises the exchanges between scientists (in the form of letters) and which created the first professional body of scientists by setting up the Académie des Sciences, whereas in England the scientists themselves organise the Royal Society. The French monarchy does expect a return in the form of progress for agriculture, industry, military art and, above all, cartography to improve the conditions of the colonial adventure. Science and political power have a common commitment: increasing welfare, technical capacities, military efficiency, navigation, and so on.

---

[133] “Science and Technology; Public Attitudes and Public Understanding of Science” in USA Indicators Report 2002, NSF, Washington D.C., Chapter 7, pp. 7-26

[134] Plato: *Republic*, VII, 528b, “the science in question is tri-dimensional geometry”

Science came to be part of the public sphere as a conversation theme among well-educated people. This was greatly helped by the early publication of novels carrying a mixture of science fiction and popularisation (such as “Empires of the Sun and the Moon” by Cyrano de Bergerac) which meet with great success. In “l’Ecole des Femmes”, Molière shows the scientific problems of the time (such as the magnet, or atoms) as part of the mundane exchanges between bright sophisticated people in the “salons”. In the 18th century, science was everywhere: demonstrations were performed at fairgrounds (static electricity or magnetism) or in shops. Popularisation books were written especially for women (for example, Newton was popularised on the continent mostly through women or by books written for women). A public of enlightened amateurs emerge in front of the professional scientists. As women are an important part of this public, it could be said that opinion there is dominated by women.

Science is also embroiled, as it is the case today, among, ethical problems because the discoveries have social consequences especially in the religious field (Galileo). The central position of Man in the Universe is challenged by the Copernic system. Published in 1543, it did not become an accepted part of educated society’s cultural background until 1708, well after the publication of the Principia (1687)[135]. This is shown in London by questions and answers in archived publications, in which scientists answering lay people try to be as neutral as possible between the two theories[136]. At that time, science was discussed in ‘cafés’ where amateurs and professionals meet, and it was also a favourite theme in Masonic lodges.

At the end of the 18th century, the encyclopaedia brings science into common knowledge in a more academic way. Leading newspapers had a scientific section early in the 19th century. Scientific conferences given by prominent scientists (such as Faraday) were one of the first science popularisation tools. The magic lantern was used in lectures for popular education, many on scientific themes. Public demonstrations in physics began early in the 18th century. The ‘universal exhibits’ were a way to promote new technologies, and to create the desire for them and hence a market. This was supported by many books and weekly or monthly magazines (especially in the golden age of science popularisation between 1850 and 1900).

7.4 Informal science education

In effect, an extensive social activity devoted to ‘informal science education’ is a classical, and long-lasting activity in Europe. The present actors are: the European Union, national governments, the scientific community and its organisations (research organisms, learned societies, academies, international laboratories or European research organisations), industrial branches or large companies, museums, science centres, and local or heritage museums. Many associations do promote science at the local, national, European and international levels.

7.4.1 The general public as a ‘target’

The dissemination activities of scientific knowledge can be divided in two types according to their ‘targets’ (in marketing slang). One is the public at large, where the intention is to deliver information on the advantages of science and technology, the state of the knowledge, and the

---

[135] In 2001, according to the Eurobarometer 55.2, 26.1% of the Europeans still believed that the Sun goes around the Earth …

[136] Anna Marie E. Ross: “Luminaries in the Natural World”, *The Sun and the Moon in England 1400-1720*, Peter Lang Publishing, New York, 2001

particular achievements of research bodies. The activities for younger people are described below.

The actions can be divided between two modes of science popularisation. The classical mode is based on what has been called the '**deficit model**', since it provides knowledge to illustrate and complement school knowledge or to provide information in areas not covered by conventional schooling. This is the traditional approach of most museums, of the internet sites of research institutions or industries, and of publications aimed at the general public. It is generally considered as part of the effort to provide a better Public Understanding of Science (PUS).

The second mode can be labelled '**two-way dialogue**', where efforts are made to establish a basis for discussion, mainly of the applications of science and technology and their consequences for society. It operates through organised debates, colloquia, visits to laboratories or factories, *cafés des sciences*, etc. Museums can also orient their exhibits in that direction, and host conferences and temporary exhibitions. Learned societies can publish journals or books, and organise round tables. Internet sites and chats can be established to collect opinion and provide answers to FAQs. Meetings can be organised by associations on specific issues (e.g. pollution).

Media and journalists usually play an important part in setting up and organising such debates. Organisation of 'science weeks' or *fêtes de la science* focuses the attention of the public on scientific issues. The festive mood profits from the easily made connections between many types of scientific achievements and basic entertainment tricks (space, images, spectacular experiments, projections into the future, mythological themes such as stories describing origins or monsters, etc.) which often provide a politically and socially neutral background (astronomy, prehistory, natural history, etc.).

It is considered that government support is shifting from the PUS model to the dialogue (or participation) mode. This can be seen from new programmes in large museums (such as the Science Museum in London or the Cité des Sciences et de l'Industrie in Paris) and from the institutional organisation of debates on controversial scientific or technical issues. However, some specialists also consider that there are no real differences between the two models because, in fact, information has to be provided if the dialogue is to be efficient, be really two-way and more than a passionate exchange of arguments. In June 1998, the Swiss referendum about biotechnology, which is one of the most recognised example of "dialogue" in Europe, confirms more or less that point of view. Dialogue there appears as a staging process which helps the academic and industrial communities to make known their intents and points of view while, at the same time, collecting and taking into account the arguments and feelings of the public.

7.4.2 Informal science education for young people

7.4.2.1 The need for attractive role models

Although youngsters are not excluded from the general public target described above, as a group they make a second, more specific strategic target. It seems important to persuade them, at an early age, of the successes and importance of science, engineering and technology and, if possible, to help them to grasp what scientific method is all about. The links between the content of research and the net benefit to society are to be clearly highlighted. Likewise, young people should be encouraged to recognise the role of research, the relevance of doing research and the value of careers in R&D. From this point of view, commitment by politicians to recognising the importance of researchers for society is fundamental. For example, there has never been a coordinated European strategy to improve and promote better public recognition of careers in R&D.

Above all, they need to identify relevant role models, especially young role models, in the SET domain. Not only must they appreciate the key contributions these men and women make to the economy and quality of life of the people of Europe, but they must also have role models whose efforts and achievements have been well rewarded, not just with fortune (Bill Gates!) but with genuine fame. Public recognition of pre-eminent status in a research profession is often limited to deference to academic titles such as 'professor' or 'doctor'. And why is it that we always celebrate the names of dead scientists but very few people know about living scientists?

7.4.2.2 Science centres

As we saw in the previous chapter, many of the activities designed specifically to interest young people require the co-operation of school authorities, which is not always easily granted. These may involve visits by scientists to the classroom, visits to laboratories, electronic mail exchanges, gifts of documentation, books, images, and so on. Fundamental research bodies, such as the French CNRS, now have an agenda of such activities.

But the most systematic channels of informal science education are **science centres**. These, and most science museums, put into operation the 'hands-on' pedagogical strategy whose implementation in school science was discussed in the previous chapter. This strategy is often said to have started in 1969 at the Ontario Science Centre and at the Exploratorium in San Francisco, and has subsequently become popular all over the world. In fact 'hands-on' has an older history, for it is implicit in the whole tradition of 'practical work' in formal science education, and there had previously been 'interactive' exhibits in Europe, such as at the Palais de la Découverte in Paris, since 1937, and at the Children's Gallery of the Science Museum in London, since 1931.

Specially constructed exhibits encourage interaction and visitor participation. The intent is to induce youngsters to perform simple experiments which provide an explanatory background for basic scientific principles. Although children are free to visit them with their parents, school groups often make up the bulk of visitors.

There are numerous science centres and museums in Europe with exhibits of this type, sometimes among other displays. Indeed, 35 million European citizens, of whom 37% are youngsters, visit science centres and museums in Europe every year[137] – i.e. about 10% of the whole population of Europe.

The establishments can be divided in three types: the bulk of ordinary museums and science centres; the four big museums in Europe (the two London Kensington Museums, Science and Natural History, the Deutches Museum in Munich, and the Cité des Sciences et de l'Industrie in Paris); and the conglomerate of more leisure- and tourism-oriented places: zoos, aquaria,

---

[137] Numbers given below are taken from the museum chapter in the Report "Benchmarking the Promotion of RTD culture and Public Understanding of Science 2002"

and botanical gardens. Medium-sized science centres have younger visitors (65% are under 25), but only 46% of visitors to the 'big four' are under 25, while significant numbers are from abroad. The smaller venues enjoy a large number of young visitors besides attracting local ones. The big institutions receive their money from public sources, but the smaller ones have to fight to get support.

The impact of science centres and museums on education has been the subject of a number of studies giving contradictory results[138]. Students enjoy visits and, as a result, may be more interested in science studies. Their understanding of science is improved and they may be induced to pursue science careers. Other observers have concluded, however, that the highly interactive environment of museums is not associated with effective learning outcomes. The teams of youngsters visiting museums as class groups are usually very agitated and excited. They run around and laugh and obviously have a very good time, but they do not seem to learn very much. Nevertheless, the unusual setting may have an influence of its own, by *impregnation*. For instance, it may nurture daydreaming about being a scientist – many present-day scientists recall their childhood visits to science museums.

Much more efficient as a medium for informal learning is the situation where young people visit with adults – typically parents or grandparents. This often comes after the class visit. The exhibits are then the object of two-way explanations, the child sometimes being the guide. Much more attention is then given to the displays along with more attentive listening to those giving the explanations.

The role of the staff in science centres and museums is very important. The personal quality of their interactions with visitors has a tremendous effect on the efficiency of the visit, especially when the displays are complex or when it is difficult to make sense of them because of the fragmented postmodern style of exhibition. Demonstrations always make good shows and may be convincing and easy-to-remember science lessons.

There is still much to discover about the long-term impact of such visits on learning, or having opinions about SET. There are detractors of science centres who consider they are just fun palaces, manipulating a populist approach to science, with many worn-out displays, or exhibits which do not work, and generally gloomy in appearance. Sir Neil Cossons, Chairman of English Heritage, declared in an address entitled 'Industrial Museums in the New Millennium': "*When young people themselves view science as something they finished with as children, small wonder that puberty appears to be the great enemy of the public understanding of science. Science centres, set up to inspire and engage, may in fact be laying the ground for a conscious and forthright rejection of science by the young once they become aware of more appealing alternatives.*"

7.4.2.3 National efforts

There are several initiatives in Europe to improve communication of science to the public and/or to attract more young people in scientific careers[139]. Thus, in the UK, science popularisation is an established tradition and is supported by the state as well as by private entities such as the Wellcome Trust. In France, the French Academy of Sciences has launched and supported an initiative called 'La Main à la Pâte' which brings hands-on *into* the

---

[138] References are given to specific papers in the museum chapter and in the Annexes of the Report "Benchmarking the Promotion of RTD culture and Public Understanding of Science 2002"

[139] See: "Benchmarking the Promotion of RTD culture and Public Understanding of Science 2002"

classroom with a choice of simple experiments designed to make the scientific method better understood. For several years now (1996-2002), a very active policy has been conducted in Portugal by the Ministry of Science and Technology under the heading ‘Ciência Viva’ (leading to the creation of a non-governmental national agency for scientific and technological culture: Ciência Viva, www.cienciaviva.pt), to promote scientific learning in schools through experiments and inquiry-type researches. It has also encouraged the co-operation of scientists and university teachers with the classroom and their interaction with general public, as well as the creation of science centres all over the country.

In France, however, although science popularisation is a rather well-developed activity (e.g. the four big national science and technology oriented museums in Paris), the many associations working in the field complained recently of the growing loss of interest by the state and lack of support, especially financial, for their activities, even in a context where it is necessary to explain to a large public several major scientific issues (biotechnology and climate change, for instance) and to boost the interest of the young in science careers[140]. This feeling prompted the French Senate to produce a report[141] and the government to assign a mission to a Member of Parliament (due in February 2004). But the history of the French popularisation of science is clouded with reports which, year after year, reproduce (independently!) the same analysis …

7.4.2.4 Instability

Science popularisation suffers from dependence on political will. The policy of support action varies with the political colour of the governments (as shown by the Portuguese example above). The availability of money and other economical or social reasons also contribute fluctuating factors. Research agencies, for instance, may have to cut short their communication policy at times of financial hardship. This is also true for the industries involved (mostly through websites) in science communication programmes.

Another cause of instability is the fluctuation of school programmes, depending on pedagogical moods or trends, changes in curricula, or teaching time allocated to the several academic fields, security constraints which do not allow children to leave school, for example, to visit a museum, and so forth.

Media themselves are subject to change or can disappear because of economical reasons. As a consequence, many science popularisation activities, particularly those directed by the scientific community, governments or industry, are short-lived. Museums, educational institutions, and media are more stable actors but can also change behaviour and policies.

7.4.2.5 The urban issue

An important parameter in science popularisation is the geographical one. Many of the actors and facilities are concentrated in large cities. In Europe, four science museums – two in London, one in Munich and the other in Paris – dwarf the others by a wide margin in terms of resources and visitors. Smaller structures are to be found in big or small cities all over Europe but only heritage (*Heimatmuseen*) and local interest museums are widely distributed. This is

---

[140] ASTS: “Assises Nationales de la culture scientifique et technique”, *Axiales* (Hors série), février 2004, 165 pages

[141] Marie Christine Blandin et Ivan Renar: “La culture scientifique et technique pour tous: une priorité nationale”, *Rapport d’information* 392 (2002-2003), Commission des Affaires Culturelles du Sénat

because they are witnesses to historical periods prior to the time of countryside emigration or industrial concentration. Thus they very often depend on the support of a local industrial branch of which they exhibit the history.

The human dimension of those small places, and the easily understandable displays they usually have, make them an important potential medium for the promotion of technology or science. But they are not well known and information on them is available but may be scarce. They represent places where memories are kept of past technologies and ways of life, sometimes with a touch of nostalgia. The development of open-air museums in Scandinavia at the end of the 19th century was in response to the tragic decline of agricultural communities in the face of rising industrialism, and was a consequence of the weight of *Natürphilosophie* in northern countries. The same nostalgia drove the emergence of the '*écomusées*' in the French countryside in the 1970s.

The problem of promoting science is not an easy one in areas of large urban density. It is difficult to communicate within a great concentration of people where many messages are competing for audiences. The advertisements displayed on walls and newspapers for science events (exhibitions), or popular monthly science journals, may be misleading the public. Very often they use spectacular terms or provocative images to try to attract attention, giving an overall vision of science as a sensational activity devoted to trying to travel in time or to manipulate the human body. This gives science a bad, aggressive image, even though it is often caught only 'subliminally'.

7.4.2.6 The complexity of museums

Museums, when they are old, are urban monuments dedicated to the power of science and industry. Nowadays, they function as a superposition of historical layers, such as:

- The traditional collection museum ('natural history' or 'machines') which is like an archive for scientists and where other visitors may not feel welcome.
- The museum which is basically a pedagogical and practical illustration of science at school.
- The museum as a showcase built to celebrate the achievements of the scientific community, or of a particular research body.
- The hands-on museum or science centre.
- The museums which present the uses and social consequences of technologies rather than the basic scientific principles.
- The 'history of science and industry' museum, exhibiting relics of the industrial age, sometimes '*in situ*'.
- The museum devoted to debates and social issues.
- And now we face the science museum as a component of a 'show' society, along the lines of entertainment parks.

It may happen that many of those components are alive in the same establishment. As society shifts away from its industrial history, it may be interesting to profit from this diversity to gain a better insight into the past and the future, and enjoy the present, even if this includes some degree of show. Meanwhile, the visitors can have a feeling of being quite lost. This is why smaller places have more attentive but, of course, much smaller audiences.

Because of their complex history, museums are not neutral places; they are the symbolic translation of an ideology on the city's grounds. The origin of museums[142] is sometimes political: the will to provide a showcase for a powerful industry (the Deutsches Museum in Munich, 1903). Some (the South Kensington Museum, 1857) are connected with the intention to provide people with an education which could be helpful for future industrial employees. Others (the Conservatoire des Arts et Métiers in Paris 1797) were designed to display to everybody machines and processes formerly hidden in corporation secrets. In each case, the basic purpose is educational.

Museums have evolved since their birth but most of them remain urban monuments in the great neo-antique style, or are examples of modern design (the Cité des Sciences et de l'Industrie in Paris, and many smaller places elsewhere from Amsterdam to Valencia in Spain). Designed, like ancient pagan temples, as material embodiments of the greatness of science and industry, to be visited with utmost respect, they are becoming more of a public forum where opinions can be voiced. This is the strategy behind the new wing of the London Science Museum, the Wellcome Wing, dedicated to explanations about biology and discussions with the public.

7.4.2.7 Exclusivity (élitism)

The challenge facing Europe today, which is to increase the number of scientists and engineers available for research and development, was met by other powers before, and was solved by the lure of élitism. For instance, the French revolutionaries, faced with a shortage of human technical military capabilities, tried a mass education effort (*l'Ecole Normale de l'an III*) first, with the help of the scientific community, but it failed. Then, in 1795 they created the '*grandes ecoles'* whose students were chosen through a selection process based on their ability in mathematics (this is still going on today, but for the fact that most graduates now go into administration or business). Of course, employment was guaranteed for graduates from *grandes ecoles* (and is still more or less so today, although their number has increased).

The European Union is certainly financially capable of supporting bright students through selected studies of interest for European plans. And this can certainly be achieved whatever the state of opinion, or even the consent, of movements which are against science, technology or even learning. However, the question of the political acceptability of such a selective process remains open. What is more, it might even be counter-productive as it would further repel from the SET workforce the large numbers of young people who are not 'bright' by academic criteria but who are perfectly capable of being trained to become invaluable members of R&D teams.

---

[142] Brigitte Schroeder-Gudehus (editor): "La Société industrielle et ses musées; Demande sociale et choix politiques", 1890-1990, *Editions des Archives Contemporaines*, Gordon and Breach, Montreux, 1990

7.5 Science and the media

7.5.1 The communication from institutions

Every research organisation, research centre, university and the like in Europe has a communication policy directed towards the media and has communication officers among their personnel. Their goal is to inform the press on their activities, describe advances, promote scientists, and organise visits to their facilities. They hope that the facts and information presented will be chosen as subjects of articles or at least included in a series of short news reports. In addition, the officers try to establish some sort of personal relationship with influential journalists. This communication strategy is designed to improve the image of the organisation and to arouse public interest.

Political bodies are also interested in the communication of science to the public in order to get support for public investment in science and technology. The competitive and dynamic image associated with knowledge is promoted by every nation as well as by the European Community. Consequently, pressures are put on research organisations and scientists alike so as to make them give more of time to science communication, which is what they do in a variety of ways and directly with the public, depending on national cultures and habits. However, the importance for the media to reach a large number of people implies a special approach. Journalists get a large amount of information from research bodies. The Alpha-Galileo internet databank provides them with press releases from many such organisms, although European journalists also use the US facility EurekAlert, a service from the AAAS (American Association for the Advancement of Science). It can be said that the efforts of the institutional communication covers the field of information on what the scientists are doing in Europe very efficiently. The sources also include the websites of large research organisations or individual laboratories in the public or industrial spheres.

7.5.2 How the media handle science

In the political or academic world some people believe that the media has a diffusion logic for science and technology. This is supposed to be a duty for them as a public service. In the case of TV, the broadcasting stations in Europe have a slot for science, but generally not during prime time (with the exception of the BBC[143]). In general, the vast majority of the science stories proposed by the research organisations are considered either too abstract to interest the readers or viewers, or boring. Nevertheless, science is in the media and is dispersed throughout many slots in broadcasting dealing with news, economics, agriculture, and entertainment in a diffuse way, although some of the information delivered can be considered pedagogical. The main newspapers in Europe have science pages and there are numerous monthly journals which deal with science and technology. The difference with the institutional information lies in the way in which the journalists make a choice of the information they use. They usually need a story. Consequently, they tend to select from the material offered by the scientific organisations only that which can make an attractive story. But then the rules of storytelling will apply to science and technology as well[144].

---

[143] See the case study on the BBC in the media section of the "Benchmarking Report on Public Understanding of Science 2002"

[144] Paul Caro: "Science in the Media between Knowledge and Folklore", in *The Communication of Science to the Public, Science and the Media,* Fondazione Carlo Erba, Milano, 1996, pp. 111-132

An analysis of television or newspaper production, from the point of view of science journalism as a literary exercise, shows that they use classical literary tricks derived from the popular literature such as the folklore tales. They need a hero (positive or negative), places, times, exceptional circumstances, mythologies … Only a small part of scientific production can provide stories. However, if it is possible then the field concerned can become very popular and well known (dinosaurs and kids, for example). Science lessons can be provided alongside the story and be listened to and understood (for instance, elements of nuclear chemistry in the explanation of the birth of stars). The media can be very successful in teaching parts of science. The scientific community has produced very clever and famous popularisers who are used by the media as advisers on whatever scientific question emerges in the news. Nobel prizewinners, for example, are asked for their opinion on many things, many of them not scientific. But the problem is that the literary tricks used in science journalism are the same as those used by science fiction writers or even by storytellers of the 'fantastic' or of the 'false' sciences which have an enormous audience in Europe and America. The difference is, of course, in the quality of the scientific content, although the public, or at least a fraction of it, cannot usually make the difference.

The influence of fiction is growing as science provides plots for many popular entertainment productions, from TV series to Hollywood movies and comic books for children. In most of those productions, science is associated to power, either 'good' or 'evil'. The plots are built on archetypes which recall the traditional corpus of folktales themes (hence the interest in dinosaurs, for instance). Among them is the scientist as a hero, in particular working alone in the desert, or cast as an adventurer (Indiana Jones). The image of the scientist adventurer is also common in novels (Jules Verne). The 'good guy' image is important for youngsters as it may suggest a career path by imitation. This, in fact, is the case with Indiana Jones (archaeology) or the sympathetic figure of Ross in the series *Friends* on TV (palaeontology).

The images of science delivered by the media are dominated by a few factors:

- The weight of sensationalism: science provides stories which can raise emotion. Emotions are a very important component of behaviour and play a part in decisions, such as economical ones (see the GMO story). The manipulation of fear is a very common trick. For instance, the novel *The Prey* by Michael Crichton may induce fear of nanotechnologies because of the artificial insects which attack their creators. There are already signs of this …

- The feeding of iconic images, reinforcing images that are already well accepted, for example, space conquest, prehistory, astrophysics or archaeology. This is a barrier to the introduction of new subjects and confines images of science (usually 'good' ones) to special domains (and may attract youngsters to areas with little economic value), but this is part of the conventional actions in the deficit model framework.

- What the future will be. Predictions is a favourite approach for the media – some are catastrophic (the greenhouse effect) and some providing high expectations (such as fighting old age or killing cancers). Science-fiction novels or TV series play an important part in creating expectations for the future (a large number of people believe that scientists are really studying 'teleportation').

- Staging debates. There are some serious debates organised among scientific experts on TV. But the audience is more attracted to a debate programme organised with very different people who have little chance of agreeing – for instance, an astronomer and an astrologer. That makes for a lively discussion especially with witty ‘innocent’ bystanders from other fields such as show business. The anchor men in those shows maintain a neutral equilibrium between true scientists from institutions and their adversaries, a position which contributes to make relativism acceptable to society, reinforcing the idea promoted by some postmodern philosophers that truth is only relative … and science has no monopoly. When there is controversy among scientists, the media usually take the utmost care to expose the positions of both parties. This is a problem when rationality is at stake.

Nevertheless, there are excellent scientific productions by the media (various BBC series, for example) produced in co-operation with scientists. Some of them are designed for children and represent a real (and successful) effort to explain science. The media have to take the interests of their audiences into account. At the moment, anything which concerns the body comes first, including medicine, foods, cosmetics, followed by the environment, then new technologies. But there appears to be no interest at all in the academic disciplines such as mathematics, physics, chemistry, and biology[145]. In fact, there is a fair amount of science on European television now which proves that science is indeed a part of the cultural background.

Sometimes the scientific strategy and the media practice converge, but most of the time the media stay within the framework of the ‘show society’ and maintain their own view and policy when dealing with science. Consequently, it is a little delicate to think of using the media to promote science for young people, especially at the request of European authorities. It can be done, but selectively.

It may happen that scientists embattled with colleagues try to use the public through the media to defend their cause. As a consequence, the media have become suspicious if personal or corporate interests are at stake. Disputes among experts are one of the causes of disenchantment with science. However, the politically, socially, and economically neutral parts of science – such as astronomy, prehistory, animals, and plants – enjoy a wide media coverage.

7.6 Science wars

There have been periods in the history of Europe when science and technology have been vehemently criticised. The extent and social implications of the criticism makes it a characteristic of European society. This is a basic difference with the Americas and Asia. This happens at times when changes in technology are happening quickly and are causing problems in society because of the destruction of old technologies and the creation of new ones. One such period is the Romantic era (the quarrel between Goethe and the Newtonians about colour and the formulation of *Natürphilosophie*) which created a suspicion about science which was removed from classroom teaching in France in the 1830s because “it was drying the imagination of young people”. French scientists (Arago) had to fight to defend the teaching of science. Another episode just after the scientist period (1850-1895) started at the

---

[145] See the “Benchmarking Report on Public Understanding of Science 2002”

beginning of the 20th century and lasted until the end of the 1930s. It was characterised by an assault on rationality and scientific logic and the promotion of intuition as a way to access the truth. The works of the German writer Oswald Spengler had an enormous influence in Europe. As political groups sharing those views came to power, the situation became really bad. "The number of students at the technische Hochschule fell by half between 1932-1933 and 1937-38."[146] As science needs political support, it may be in a difficult situation when politicians in power are affected by the anti-science or anti-technology feelings of influential intellectuals.

Today, there is an upsurge of 'alternative' beliefs in the metaphysical, spiritual and supernatural in many western countries. These movements are often collected together under the 'New Age' label, and comprise a rich variety of world-views, practices and therapies. They include beliefs about 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.

Postmodern philosophers were considered responsible for many attacks on science and technology. Postmodernism starts from the evidence that the systems which offered either a religious or political liberation goal to their followers have collapsed and confidence in them has been lost. There is no hope any more. Science as a liberation enterprise is also concerned. As there are no more guidelines, everyone can follow whichever ideas are providing a seductive 'truth'. These may be seen as a 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 knowledge 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', and have been met with strong counter-attacks from the scientific community. Books with titles such as *The flight from science and reason* (Gross et al., 1997[147]), *Higher Superstition* (Gross and Levitt, 1998[148]), *A House Built on Sand – Exposing Postmodernists' Myths about Science* (Koertge, 1998[149]) and *Fashionable Nonsense: Postmodern Intellectuals' Abuse of Science* (Sokal and Bricmont, 1998[150]) indicate the tone of the 'conflict'. Although science as knowledge or as an activity *per se* is unlikely to

---

[146] Mokyr's book, note 26, p. 239

[147] Gross P.R., Levitt N., Lewis M.W. (eds.), 1997, *The Flight from Science and Reason,* Baltimore, MD, Johns Hopkins Press

[148] Gross, P. R., Levitt, N., 1998 [1994], *Higher Superstition. The Academic Left and Its Quarrels With Science,* Baltimore, MD, John Hopkins University Press

[149] Koertge, N., 1998, *A House Built on Sand – Exposing Postmodernist Myths about Science,* New York, Oxford University Press

[150] Sokal, A., Bricmont, J., 1998, *Fashionable Nonsense: Postmodern Intellectuals' Abuse of Science,* New York, Picador USA

be shattered by these attacks, the science war creates an atmosphere of hostility and doubt that deserves to be taken seriously.

The important question of ethics is also a subject of public interest. 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)[151] who coined the acronym CUDOS to represent them (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 is perceived as ‘cold’, uncaring and lacking a human face.

Ziman (2000)[152] has commented on the issue of values and ethics in science. He describes how recent developments in science have put even the traditional academic ethos under stress. He calls this new contemporary science ‘post-academic science’, and urges the scientific community to become more ethically involved than ever before (Ziman 1998)[153].

---

[151] Merton, Robert K., 1979 (original 1942), *The Sociology of Science*, Chicago, University of Chicago Press

[152] Ziman, J., 2000, *Real Science – What it is, what it means*, Cambridge, Cambridge University Press

[153] Ziman, J., 1998, “Why must scientists become more ethically sensitive than they used to be?”, *Science*, No. 282, pp. 1813-14

7.7 The state of opinion about science and technology in Europe

This has been measured recently (December 2001) through the Eurobarometer 55.2. General trends show an overall positive perception of science and technology. Scientific literacy is measured by a questionnaire, a true/false scientific quiz of 12 knowledge questions, (the same as in the US and Japan). There are no apparent differences with the preceding survey (1992). The European (15) average correct response is 57.8%; 43.5% of the 16 000 people surveyed were somewhat interested in science and technology. This is slightly lower than in 1992. 45% of the Europeans say they are neither interested nor informed about science and technology and two-thirds consider themselves as badly informed. The ratio of the knowledge index over the interest index shows different expectations about scientific information between the European countries. Ireland and Germany seem to be only slightly interested in the promotion of scientific culture, whereas Greece, Denmark and France seem to be potentially more involved – the other countries fall in-between these. People are more interested in medicine (60%), the environment (52%), and the internet (28%). This is confirmed by other surveys conducted by museums which show that very few people care about academic disciplines such as physics chemistry, mathematics or biology (the score in the Eurobarometer for nanotechnologies is just 4%). Even astronomy scores low: only 18%.

The main source of scientific information is television for 60% of the people surveyed; the press, 37%, radio, 27%, school, 22%, scientific journals, 20% and the internet, 17%. Of those questioned, 60% rarely read articles related to science and technology; 36% consider that science is presented too negatively by the media, and 53% that the journalists do not have the appropriate background to deal with scientific issues. The classical test on the ‘scientificness’ of different sciences shows that a little above 50% still consider astrology as a science. Other surveys show a very important degree of belief in specific parascientific themes (such as extrasensory perception).

The most respected profession is that of medical doctor (71%), then scientists (45%), and engineers (30%), while journalists (14%), business people (14%), and politicians (7%) are all well below. Knowledge is clearly connected to power. The image of scientists is, in fact, ambiguous. As regards the statement “scientists are responsible for the misuse of their discoveries by other people”, 42.8% agree and 42.3% disagree. The power of opinion-making is clearly expressed by the questions about GMOs: 94.6% want to have the right to choose but 59.4% already believe that “GMOs may have negative effects on the environment”. The level of education has no influence on that belief. A similar opinion problem is raised by a survey in France about the greenhouse effect and nuclear power plants: 60% of the French surveyed believe that nuclear plants contribute to the greenhouse effect (including university-educated people!) whereas only 10% of the Finns hold such a belief.

The part of the Eurobarometer dealing with science and the young people is especially interesting. The image of science among young people is the same as for the general population – no better, no worse. The reasons for the declining interest in scientific studies and careers are identified as follows:

59.5% say that science lessons in class are not sufficiently interesting
55% say that scientific subjects are too difficult
49.6% are less interested in scientific subjects
42.4% believe that career prospects are not sufficiently appealing

31% have a negative image of science

The American 2001 survey, which is discussed in section 7 of the USA Indicator Reports 2002, shows some parallelism with the European barometer although it uses a somewhat different analysis scheme. The tests for public attentiveness towards science and technology issues shows that the *interested* public (adult) is slightly under 50%, but the *attentive* public is only 10%. The 12 knowledge questions are the same and the degree of correct answers was classified versus the degree of education (50% for those who have not completed high school, 63% for high school graduates, 77% for college graduates, and 80% for those with a professional degree). There were additional questions: “22% of the respondents were able to define *molecule* and 45% gave an acceptable definition of *DNA*”; 30% of the respondents passed the tests designed to measure their understanding of scientific processes. A comparison of the attitudes towards science and technology in the US (2001), UK (2000), and Japan (1995) shows clearly that the Americans have a greater degree of support for science and technology.

The survey shows that there is a large degree of dissatisfaction with the education system in the US: 68% state that “the quality of science and mathematics education in American schools is inadequate”, while 90% agreed “that students needed a stronger education in science and maths to be prepared for the new inventions, discoveries, and technologies that the increased investment in research and development will likely bring”. As in Europe, medical professions, then scientists lead the public confidence list. However, a study of the public perceptions of scientists shows that the image of the scientist is strongly influenced by the frequent use as characters (mostly bad, sometimes good) by the media, movies, television, and comics. Television is also the main source of scientific information although the internet is now largely used to collect information on specific scientific issues. The degree of belief in paranormal phenomena is also quite high in American society (such as ‘aliens’ or UFO).

8 Women in science – filling the gender gaps in science and research

Summary

“Women are the most obvious source for increasing the numbers of highly trained scientists, engineers and technologists, because this talent pool already exists and can be expanded.” (Rübsamen-Waigmann et al., 2003).

The number of women in education and in employment across Europe has increased in the last 20 years, as indeed has the number of women entering science. However, women remain severely under-represented in many areas of scientific research and in many countries, and are still not reaching the upper echelons of the research hierarchies.

Much has been achieved in promoting women’s participation in scientific research since 1999, when the European Commission launched its action plan on women and science, in co-operation with Member States and other key actors. As a result, there are a number of reports and statistical documents devoted to this subject. For this reason, this section seeks only to provide an overview of the situation.

Women remain the most obvious source for increasing human resources for science and technology in Europe. However, drastic changes in the present unsatisfactory situation can only come from joint consistent efforts by both science policy and social and economic policies.

8.1 The situation

8.1.1 Interest in science at school

Interest and achievement of boys and girls at school are, of course, different for different subjects. However, research has shown that girls’ interest in physics remains lower than that of boys, as does their perception of and self-confidence in their scientific abilities (Seidel 2003, Baumert et al., 2000). As a result, the number of girls choosing to study some science subjects at secondary school level, particularly physics, computer science and engineering, is still low. For example, figures for 2002 in the UK suggest that of all girls completing secondary school education, only 2% chose to study physics.

8.1.2 Take-up of science subjects at university

Women now represent the majority (56%) of graduates in higher education in Europe, with 41% in science subjects and 21% in engineering (Strack 2003).

Table 1. **Percentages of women among graduates from tertiary education by broad field of study, 2001.**

	Total higher education graduates	Science (ISCED 400)	Engineering, manufacturing & construction (ISCED 500)
EU-15[1]	55.9%	41.0%	20.9%
Belgium	56.1%	31.4%	18.2%
Denmark[2]	56.3%	32.5%	26.2%
Germany	51.6%	32.9%	16.7%
Greece	:	:	:
Spain	57.2%	40.8%	25.1%
France[2]	55.8%	42.6%	18.7%
Ireland	56.0%	47.6%	18.0%
Italy[2]	55.9%	54.5%	27.6%
Luxembourg	:	:	:
Netherlands	54.7%	27.4%	12.3%
Austria	51.5%	39.0%	15.1%
Portugal	67.1%	58.2%	35.3%
Finland[2]	61.7%	46.4%	20.3%
Sweden	58.5%	46.5%	27.5%
UK	56.6%	37.2%	18.0%

Source: Strack, 2003
(1) EU-15 averages are estimated
(2) Data refer to 2000

There is strong evidence that women are less likely than men to progress to advanced research programmes, where they only constitute 40% of all PhD graduates (36% in science and 21% in engineering). However, the growth rates of numbers of PhD graduates are currently higher for women than for men in most European countries.

Table 2. **Percentages of women among PhD graduates by broad field of study, 2001.**

	Total higher education graduates	Science (ISCED 400)	Engineering, manufacturing & construction (ISCED 500)
EU-15[1]	39.6%	35.7%	20.6%
Belgium	31.9%	33.6%	15.4%
Denmark[2]	37.4%	32.6%	23.7%
Germany	35.3%	26.8%	11.8%
Greece	:	:	:
Spain	42.9%	44.6%	23.2%
France[2]	42.7%	39.3%	26.8%
Ireland	44.4%	42.7%	22.2%
Italy[2]	50.8%	47.7%	34.4%
Luxembourg	:	:	:
Netherlands	31.5%	25.5%	13.8%
Austria	37.1%	35.6%	13.0%
Portugal	50.7%	49.8%	39.1%
Finland[2]	45.8%	37.4%	21.2%
Sweden	39.2%	33.0%	24.1%
UK	39.5%	38.9%	18.8%

Source: Strack, 2003
(1) EU-15 averages are estimated
(2) Data refer to 2000

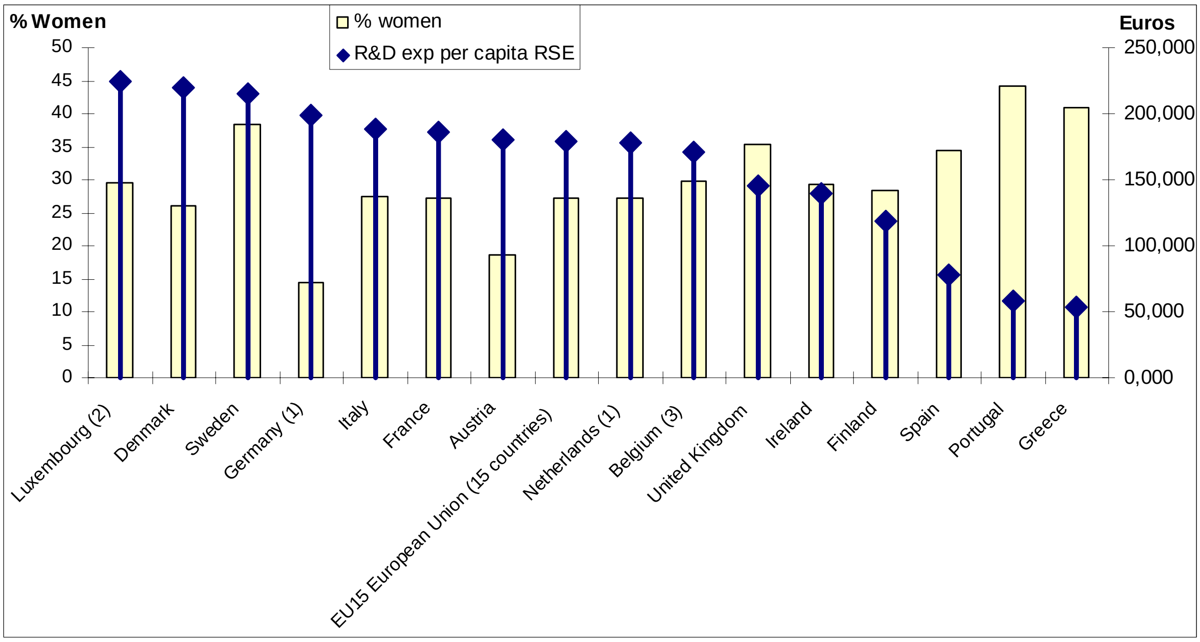
8.1.3 Gender differences across the scientific workforce

In broad terms, the distribution between men and women aged 15+ in the labour force is almost equal (51.6% women, Franco & Jouhette 2003). Women constitute just under half of the scientific workforce (HRST[154]) (European Commission 2004) and their numbers are increasing more quickly than for men. This applies equally to appropriately qualified scientists (HRSTE) and to those working in S&T occupations (HRSTO), and means that neither qualification nor occupational field can be regarded as having an impact on the representation of women in science.

Under-representation of women in strategic areas

Despite the increase in women's qualifications in the EU Member States, women are still under-represented in key domains, namely research, engineering, senior academic positions, and scientific boards (European Commission, 2003b).

Figure 1. Percentages of women among researchers and R&D expenditure per capita researcher in euros, 2001.



Source: Eurostat S&T statistics, Ergma et al., 2003

Researchers: Exceptions to reference years: EU-15: BE: 2001; DK (BES), DE (BES), EL, ES (BES), IE (GOV & BES), PT, SE (GOV): 1999; AT: 1998

Data missing: BE, NL (GOV & BES missing); LU, SE, UK (BES missing)

(1) FTE as exception to HC: DE; IE (GOV + BES); NL (HES); SE (GOV)

(2) Data provisional

(3) Data not official

R&D expenditure data: Exceptions to reference years: AT, UK: 1998; EL, SE, FI: 1999

Women account for only one-quarter of all Europe's researchers: 34% of researchers in the higher education sector are women, as are 31% of researchers in government research institutions. In industrial research, the proportion of women researchers is 15% in the ten countries for which the data are gender specific. This figure ranges from 9.6% in Germany and 9% in Austria, to 17.8% (Finland) and 28.2% (Ireland). Overall, women are better

---

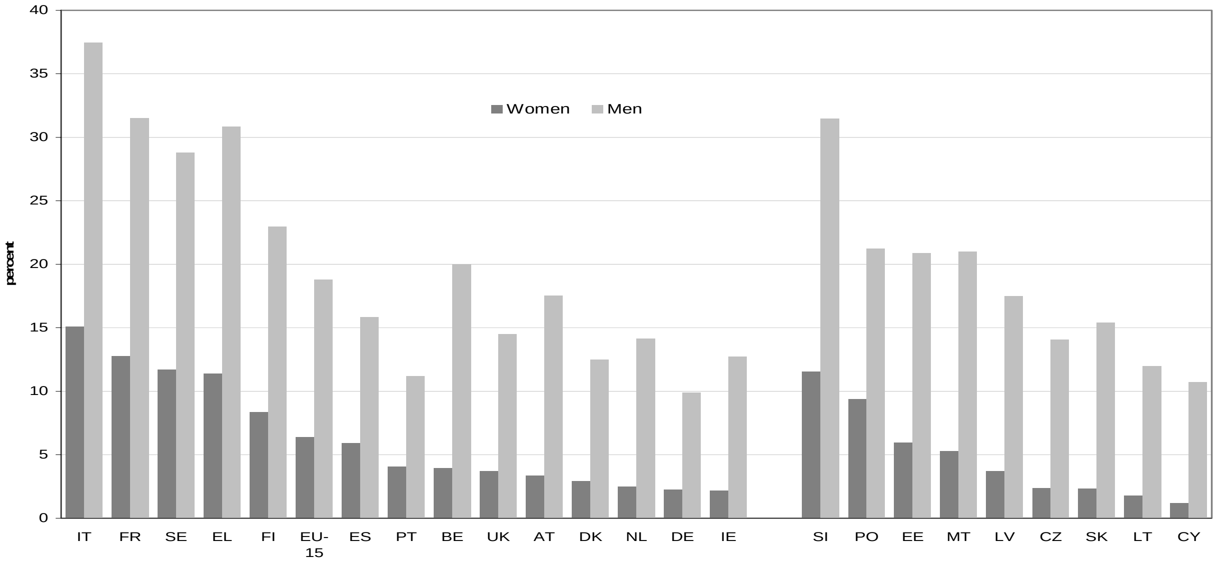
[154] Human Resources in Science and Technology (see OECD 1994)

represented in the higher education sector where there is relatively low R&D expenditure per capita: 21% of Europe's R&D is performed in this sector by 55% of all researchers. Conversely, 65% of European R&D is performed in the business enterprise sector by just 32% of all researchers of whom, as mentioned above, only 15% are women.

Engineering and technology remain male-dominated in both employment and education. The percentage of women in engineering research in the higher education sector ranges from 9% in Austria to 29% in Portugal.

Analysis of senior university staff reveals a serious dichotomy in career outcomes for men and women in academia, where men are three times more likely than women to reach the most senior levels. Although there was a slight increase for women in the top grades of university staff from 1999-2000, the average percentage (13.2%) of women in senior academic positions in the Member States has no common measure with the overall percentage for all women in all academic positions (31%). Analysis by field of science reveals that even in the most 'feminised' fields (humanities and social sciences), women are under-represented in senior positions.

Figure 2. **Percentages of academic staff (women and men) who are full professors (or equivalent) in EU Member States and acceding countries, 2000.**

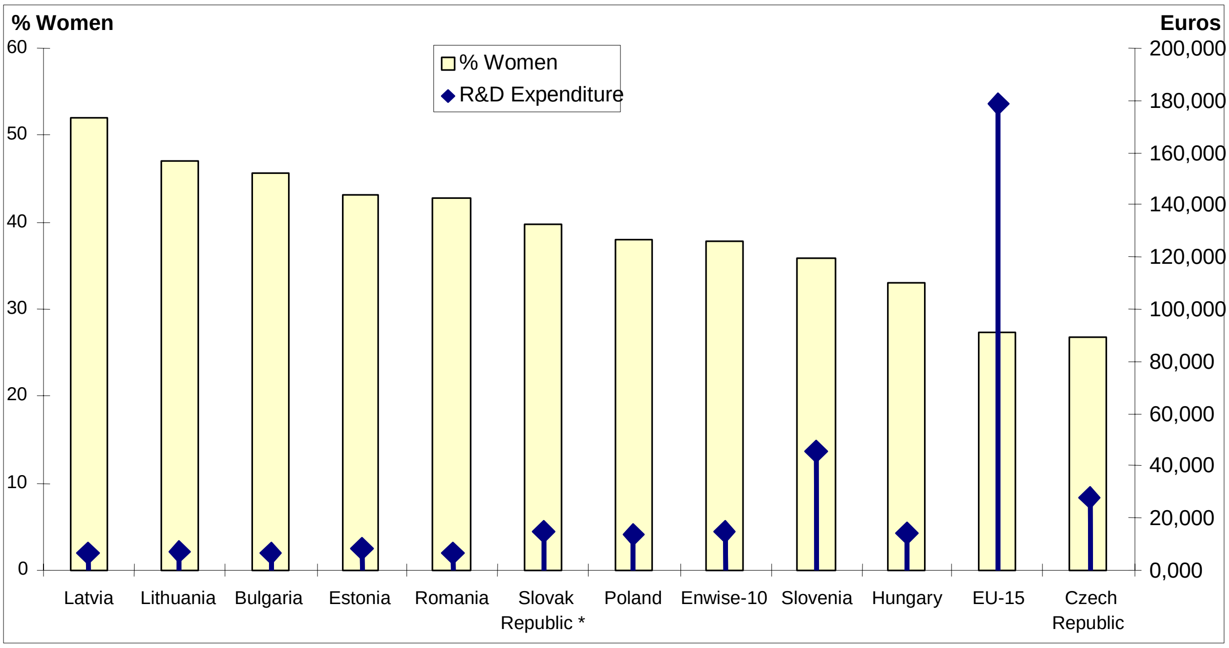


Source: European Commission 2003
Exceptions to the reference year: DE, IT, SE, CZ, EE, LV, LT, PO, SK, SI: 2001; BE, ES, PT, MT: 1999; AT: 1998; NL and PT full-time equivalents. Headcounts for other countries
No data available for LU and HU
Data are not yet comparable between countries due to differences in coverage and definitions

The scarcity of women in senior positions in science inevitably means that their individual and collective opinions are less likely to be voiced in policy- and decision-making processes. The data on the composition by gender of scientific boards show that women are under-represented in all countries except Norway. If women scientists are not visible and not seen to be succeeding in their careers, they cannot serve as role models to attract and retain young women in scientific professions (this is particularly the case for the 'hard' sciences and engineering, for example).

Women in science in an enlarged Europe
In the Central and Eastern European countries and the Balkan States, the overall proportions of women researchers are generally higher than in the Member States. At 52%, Latvia has the highest percentage of women researchers in the public sector of all European countries. The corresponding EU-15 average is only 33%. However, these percentages fail to put into context the size and economic situation of the research communities in the countries concerned, giving a misleading impression of the situation of women scientists in these countries where research communities are small and relatively poorly funded (Ergma et al., 2003b).

Figure 3. **Percentages of women among researchers and R&D expenditure per capita researcher in euros, Central and Eastern Europe and the Baltic States (Enwise-10), 2001.**



Source: Eurostat S&T statistics, Ergma et al., 2003
*FTE as exception to HC

Impact of family situation
Family situation impacts differently on men and women researchers: at European level, only 28% of female industrial scientists have at least one child under 16, compared to 35% of men. With the exception of Portugal, in all countries the gender employment gap by family situation for highly qualified women and men is much wider among those who have dependent children than among those who do not: the percentage of highly qualified women with children who are working is 79% compared to 96% of men.

8.2 Recommendations

“Gender mainstreaming: Instead of targeting the ‘special needs of the disadvantaged group’, it focuses on practices and policies that give rise to that disadvantage in the first place.” (Rübsamen-Waigmann et al., 2003)

The phrase commonly used to describe what happens to women in science is the ‘leaky pipeline’, the notion being that women ‘leak out’ of science in disproportionate numbers at every stage of the career path, in particular after the postdoctoral level. Direct forms of discrimination against women in science have been removed and formal equality exists, thanks to equal opportunities legislation in education and employment. However, actual equality is far more difficult to achieve.

If further progress is to be made, close attention needs to be given to the reasons why women ‘leak out’, and appropriate strategies need to be built to keep them in. Recommendations in this respect may include:

- Continued implementation of a **gender mainstreaming** approach in research policies at Member State and European level, to address more consistently both the under-representation of women in science and the lack of attention paid to gender in research content.

- Collection of **new gender-sensitive data** and the construction of good indicators. Subjects such as impact of the family on scientific careers need to be investigated more extensively, as does the effect of policies designed to retain and promote women and men in science.

- Encouraging a **change in work culture**, with emphasis on policies and support systems that favour the integration of work and life outside work for women and men. This could include, for example, new models for childcare, flexible working hours and places, support for re-entries (after maternity leave), and support for family mobility (not only for one member of the family), among others.

- Mechanisms for involving women scientists more actively in the **policy process**, and in designing and managing research programmes and resources, at national and European levels. Support could be provided through networking and mentoring systems.

- Measures to engage **girls and young women** in science, namely by taking account of gender differences in science teaching, improving the image of science, engineering and technology, and adapting careers materials and services to attract girls and young women into scientific professions.

8.3 References

Dunne M. (2003), “Education in Europe, Key Statistics 2000/2001” in *Statistics in Focus*, OPOCE, Luxembourg, Catalogue Number KS-NK-03-013-EN-C, ISSN 1024-4352

Ergma et al. (2003), “Waste of Talents: turning private struggles into a public issue. Women and Science in the Enwise countries”, OPOCE, Luxembourg, EUR 20955 EN

European Commission (2002): The Helsinki Group on Women in Science. National Policies on Women and Science in Europe

European Commission (2003a): “Third European Report on Science and Technology Indicators – Towards a Knowledge-based Economy”, OPOCE, Luxembourg, 451pp, ISBN: 92-894-1795-1

European Commission (2003b): “She Figures 2003”, OPOCE, Luxembourg, 118pp, ISBN: 92-894-5812-7

European Commission (2003c): “Key Figures 2003-2004”, OPOCE, Luxembourg, 96pp, ISBN: 92-894-5814-3

European Commission (2004): “Statistics on Science and Technology in Europe. Data 1991-2002”, OPOCE, Luxembourg, 173pp, ISBN: 92-894-6823-8

Franco A. and Jouhette S., (2003), “Labour Force Survey, Principal results 2002, EU and EFTA countries”, in *Statistics in Focus*, OPOCE, Luxembourg, Catalogue Number KS-NK-03-015-EN-C, ISSN 1024-4352

Kultusministerkonferenz (D): Schule in Deutschland – Zahlen, Fakten, Analysen 2002
Baumert et al. (2000): TIMSS/III

Frauen geben technik neue Impulse e.V. (ed.) (2002): Zukunftschancen.
OECD, (1994), “Manual of the measurement of human resources devoted to S&T” – Canberra Manual, OECD, Paris, 112pp

Rübsamen-Waigmann H. et al., (2003), “Women in Industrial Research – A wake up call for European Industry”, OPOCE, Luxembourg, 80pp, ISBN 92-894-4400-2

Seidel, T. et al. (2003): “Interest and motivation in physics”, paper presented at the EARLI conference 2003

Strack G., (2003), “Towards a European knowledge-based society: the contributions of men and women”, in *Statistics in Focus*, OPOCE, Luxembourg, Catalogue Number KS-NS-03-005-EN-C, ISSN 1609-5995.

CONCLUSIONS AND POLICY RECOMMENDATIONS

The High Level Group (HLG) on Human Resources for Science and Technology is part of the Commission's strategy to address the Lisbon EU Summit declaration of March 2000: that Europe should become the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion. Since the Lisbon declaration, heads of state and government across Europe have continued to stress the need to boost substantially the number of people entering science and technology careers. Indeed, at the 2002 European Summit in Barcelona, heads of state called for an increase in the proportion of European GDP invested in research from 1.9% to 3%.

In terms of human resources, it was estimated that an extra half a million researchers (or 1.2 million research-related personnel) were needed to meet that goal and reach the minimal level of eight researchers per thousand in the workforce. However, this objective will not be reached within a reasonable time (and certainly not by 2010, the target set by the EU Summit) should the present trends continue unchanged.

There is even a risk of a future decrease in the numbers of highly qualified tertiary level graduates (PhDs) in several SET fields. Students entering university can react quickly to changes in the labour market by shifting to another, more promising sector, but this is not the case for graduates who are stuck with their specialisations after several years of study and may fall victim to an unfavourable economic cycle. This shows how important it is to provide counter measures to prevent the loss of valuable human capital.

Europe would be able to catch up with the US and Japan if employment in R&D were available to young people in Europe, if the numbers of those who choose to study SET were not allowed to diminish, if more women were involved in R&D, and if the Southern European countries accelerated their SET development. In particular, achievements in education and a rapid reduction of the unacceptably high drop-out rates in many European countries could be key policy objectives to broaden the qualification pool for SET professions.

There is clearly a need for a common European policy in this area that goes beyond the post-Lisbon open method of coordination of national policies. Europe needs a common policy for human resources. We suggest that such a policy should be initiated in the area of science and technology resources and should integrate the economic, social and educational dimensions needed to reduce the persistently large untapped human resources in Europe.

We also suggest that there is a need for an observatory of human resources for science and technology in Europe, either as a separate entity or as part of a broader European science and technology policy observatory. An entity of this type could easily be created as a 'light' and non-permanent independent body. It should be given the mandate to record and analyse national and European policy measures relevant to the objective of increasing human resources for SET, and to prepare a coherent set of indicators relevant to the policy issues at stake at national as well as at European level.

The proportion of women in SET careers is unacceptably low in many European countries. Although considerable efforts have been devoted to the analysis of this problem and lip-service has been paid in many policy declarations, we feel that it is now time to act. Europe simply cannot reach the level of SET resources needed for its development without finding ways to remove its anachronistic science gender imbalance. It seems almost inconceivable that at the beginning of the 21st century European countries in need of both innovation and increasing birth rates still do not consider it a matter of social priority to provide universally available kindergartens and schools which are open all day. This is a matter of general social policy of enormous impact in science and technology policy and requires immediate action at European as well as at national and regional levels.

As most of the employment opportunities for researchers are created by industry, better conditions for the development of research in and by the private sector have to be generated in Europe if the Lisbon and Barcelona goals are to be met.

On the other hand, the level of public funding per researcher in Europe is clearly well below that of the US. It is not surprising, therefore, that the number of European researchers, notably in the public sector, does not translate into the same level of working conditions and, consequently, of results. The conditions and prospects for employment in the public sector (in universities, public research centres or other publicly funded research institutions) should be recognised as critical for the EU strategy. New human resources for SET will not be attracted at the required level unless governments translate their own political goals into new research jobs and better career perspectives. In periods of economic slow-down, this conclusion needs to be even more strongly underlined.

From a supply perspective, it can been argued that with the present trajectory of (slowly) increasing numbers entering SET careers, EU ambitions will not be met. There is a need for step-changes in recruitment into SET at all levels.

A dramatic increase in the number of women entering SET careers would go a long way to help solve the problem, whereas reliance on importing suitably qualified workers from outside the EU is not a sustainable, long-term solution, given the global nature of the market and the dynamics at play. However, we think that European science and technology policy should be addressed as part of the European Union’s broader foreign policy. The EU should compete at world level to attract qualified human resources, notably in SET areas, and combine this effort with a clearly defined promotion of its commitment to social and economic development. A better coordination of national policies and the design of a European policy to attract talents from the rest of the world are clearly needed.

It should not be forgotten that the EU itself is a source of SET workers for other knowledge-based countries. In combination with an ageing SET population, a growing shortage of teachers and the greying of academic staff, the situation is indeed serious.

It is also apparent that the shortage of human resources in SET is not felt across the whole of Europe, although it is argued that this in itself is not a steady state and that migration to satisfy demand will surely occur. The need for standards in education and qualifications will be necessary if the European Research Area is to succeed. The Bologna Process addresses such needs but it will only be successful if it fully embraces credit transfers and not time served on academic courses.

Radical solutions should be found. These must include the commitment to inject significant portions of both national and EC budgets into solving the problem. Human resources and SET should be adopted as priority budget areas across Europe in the next economic cycle.

Despite the risk arising from employment uncertainties – an aspect that must be true for every sector of the economy these days – industrial careers are shown to contrast with careers in academia and the public sector in general. Remuneration in the public sector is poor and career structures are not conducive to attracting both the quality and quantity of researchers required. Although there are other aspects of employment that do attract people to this sector, they are not sufficient to tip the scales in favour of large numbers of people wanting to enter these professions. This is certainly an area that needs the full spotlight of national and European policy, as there are serious deficiencies now that need urgent remedies.

There is a general hasty conclusion which suggests that the main emphasis on closing the 3% gap lies with industry, so industry needs to promote careers in a more attractive way to prospective SET employees. However, it is not a job for industry alone. National governments as well as the European Commission have a significant role to play and it is only through a coordinated approach that the problem can be solved. Good, well-remunerated, attractive careers in the public sector and academia need to be put in place and marketed as such to future generations if the entire European Research Area and a knowledge-based economy are to be fully realised. This is absolutely key to the future prosperity and competitiveness of the European zone.

Instead of presuming that all their science, engineering and technology students are headed for academic careers, universities should cater for and celebrate the whole range of research employment opportunities, including the relatively less-prestigious jobs that many of their graduates will actually be taking. On the other hand, opening research laboratories and industries to undergraduates would promote a more realistic perception of research by students and could effectively contribute to increasing rapidly human resources for SET in Europe.

It can be argued that science education in schools lives in a world of its own. It is unsophisticated because it is unable to compete with the advances made in the scientific fields. It is perceived as too abstract because it is trying to teach fundamental ideas without sufficient experimental, observational and interpretational background, without showing sufficient understanding of their implications, and without giving students the opportunity for a cumulative development of understanding and interest. And it is in danger of being excessively factual because of the explosion in scientific knowledge and the constant ‘adding-on’ of topics to an already extensive curriculum. This is an area in need of interdisciplinary research in relation to the European objectives.

While students see and may even interact with medical practitioners, and are familiar with the many technology products that have been developed, they lack opportunities to experience careers in industry or research institutions at first hand. Making students aware of scientific life in ‘the real world’, and of the ways in which industry operates, are all important elements – but they are no substitute for the ‘real thing’.

We wish to highlight the importance of science teachers in this respect. National and European programmes aimed at increasing human resources for science and technology should pay due attention to the increasing need to share these objectives with both scientists and science teachers, as their joint efforts are required to successfully address the challenges of science education. A European dimension should be added to this issue in view of the common European objective of attaining a larger flow of human resources qualified in SET.

Strategies for science popularisation and for the promotion of scientific culture across society are in place in most countries. Governments, public institutions, foundations, research organisations, scientists, museums and science centres usually support such strategies whereas the involvement of industry is too modest.

Classical public understanding of science tries to bring more information and knowledge about science matters to young people and to the public in general. A complementary and more promising networking approach is based on the idea that extended dialogue and direct contact between citizens and scientists, schools and research organisations, is necessary in order to promote scientific culture in society and to help citizens to acquire a better understanding of what science and technology are all about. Controversial issues related to science and technology, as well as to the science base for dealing with risk, are increasingly a part of these new approaches.

There is an urgent need for a comprehensive European strategy for scientific culture across Europe. The critical importance of this issue is clearly not proportionate to the very modest means allocated to “science and society” in the EC budget. We urge the European Commission to address this issue.

Certain economists doubt that actions to improve the popularisation of science and science teaching at primary and secondary levels are of assistance when it comes to recruitment into science careers. They believe that the most important point, on which efforts should be concentrated in Europe, is at university level. They advocate that the creation of élite higher education institutions in Europe should be the main policy objective. We do not agree with these views which, in our opinion, disregard the social and cultural context of scientific development in democratic societies and the need to reinforce and widen the social constituency able to support scientific and technological development and, notably, the very wish to study science and pursue science and technology careers.

We share the objective of pursuing research at the highest possible level through the appropriate evaluation and funding methods and the required strengthening of research institutions and teams. We think that basic as well as industrial research is in urgent need of a significantly higher political priority in Europe.

It would be counter-productive to see scientific and technological excellence as opposed to the need to broaden the scientific and technological human capital in Europe. We believe that scientific and technological excellence can only be achieved in Europe if there is a sharp increase in human resources for science and technology. At the same time, only the economic impact of scientific and technological excellence and innovation and its social perception will provide the jobs and the attractiveness needed to sustain the growth in the number of people who will choose to study SET or to vote for increasing R&D budgets.

Annex - Consultation Process: Increasing Human Resources for Science and Technology in Europe

The table in annex lists all organisations that were invited to express their views as part of a Europe-wide consultation process that was held between August and November 2003.

Almost two hundred national and European Industrial organizations, Universities and Research laboratories, Science and Technology Funding Agencies and Research Councils, Academies, Scientific Societies, Science Centres and Science Museums have devoted considerable efforts in providing the HLG with their views.

In parallel a special consultation process was also launched, to seek the views of European governments on this issue. Written national contributions will be included as a special Annex in the final report.

The HLG are therefore greatly indebted to the many individuals and organizations that have devoted considerable energy, competence and time to help us and we would like to thank them all for their invaluable support.

Consultation Process
Increasing Human Resources for Science and Technology in Europe (July-Nov. 2003)

Name of the Organisation	**Given Name**	**Surname**
Austrian Science Fund	Chairman/	President
AVL List GmbH	Helmut	List
Photonics Institute	Arnold	Schmidt
TAFTIE - Association for Technology Implementation in Europe	Gunther	Krippner
ACA - Academic Cooperation Association	Bernd	Wächter
Assemblée des Régions d'Europe, Bureau de Bruxelles (ARE)	Stéphane	Cools
Association of European Chambers of Commerce and Industry (EUROCHAMBRES)	Christoph	Leitl
Association of European Operational Research Societies (EURO)	Philippe	Vincke
Club of Associated Research Organisations (CLORA)	Michel	Billotte
Comité Èconomique et Social Européen	Patrick	Venturini
Committee of European Union Shipbuilders' Associations (CESA)	Reinhard	Lüken
Confederation of European Paper Industries (CEPI)	Teresa	Presas
Confederation of the Food and Drink Industries of the EU (CIAA)	Robert	Raeber
COST - European Co-operation in the field of Scientific and Technical Research	Gösta	Diehl
EARMA - Association of Research Managers and Administrators across Europe	Frank	Heemskerk
EARTO - European Association of Research and Technology Organisations	Jan	Dekker
ECSITE	Walter	Staveloz
ERT - European Round Table of Industrialists	Wim	Philippa
ESBA - European Small Business Alliance	Brian A.	Prime
ETIC - European Telecommunication Industrial Consortium	Philippe	Goossens
EURASHE - European Association of Institutions in Higher Education	Roland	Vermeersch
EUREKA	Michel	Vieillefosse
European Association for Bioindustries (EuropaBio)	Feike	Sijbesma
European Association for Railway Interoperability (AEIF)	Werner	Breitling
European Association of Automotive Suppliers **(**CLEPA)	Jurgen	Harnisch
European Association of Craft, Small and Medium Sized Enterprises (UEAPME)	Andrea	Bonetti
European Automobile Manufacturers Association **(**ACEA)	Ivan	Hodac
European Chemical Industry Council, CEFIC	Alan	Perroy
European Chemical Society - Université Catholique de Louvain	Jean-Marie	Lehn
European Commission	Achilleas	Mitsos
European Community Shipowners Association (ECSA)	Alfons	Guiner
European Confederation of young entrepreneurs (YES FOR EUROPE)	Tjarke	de Lange
European Construction Industry Federation (FIEC)	Laetitia	Passot
European Consumers' Organisation (BEUC)	Sheila	McKechnie
European Council for Automotive R&D (EUCAR)	Ivan	Hodac
European Council for Construction Research Development & Innovation (ECCREDI)	Scott	Steedman
European Federation of Biotechnology (EFB)	Pierre	Crooy
European Federation of Pharmaceutical Industries and Associations (EFPIA)	Brian	Ager
European Group of Owner Managed and Family Entreprises (GEEF)	Hans H.	Stein
European Regional Information Society Association	Juliette	Crowley
European Trade Union Institute (ETUI)	Maria Kristina	Jepsen

Federation of Enterprises in Belgium **(**VBO-FEB)	Tony	Vandeputte
Femmes Européennes des Moyennes et Petites Entreprises (FEM)	Erika	Seige
Forum of University Research Authority Directors (FURAD)	Shabtay	Dover
Fund for Scientific Research - Flanders	José	Traest
Gate2Grow Finance Academia	Uffe	Bundgaard-Joergensen
Group Business Development and TechnologBekaert Advanced Materials	Guy	Haemers
Laboratoire de Pédagogie des Sciences	Cécile	Vander Borght
Marie Curie Fellowship Association	Dagmar	Meyer
National Fund for Scientific Research	M.-J.	Simoen
Network of Universities from the Capitals of Europe (UNICA)	Kris	Dejonckheere
The European Medical Technology Industry Association (EUCOMED)	Maurice	Wagner
Union of European Railway Industry (UNIFE)	Drewin	Nieuwenhuis
Union Wallonne des Entreprises (UWE)	Jean-Jacques	Verdickt
FEANI - European Federation of National Engineering Associations	Philippe	Wouters
Technopolis (member of ECSITE)	Erik	Jacquemyn
Royal Belgian Institute of Natural Sciences	Olivier	Retout
European University Association	Inge	Knudsen
Ministry of Education and Science	Albena	Vutsova
Biozentrum der Universität Basel	Werner	Arber
CERN - European Organisation for Nuclear Research	Luciano	Maiani
Conference of Swiss Scientific Academies	Chairman/	President
Consortium Linking Universities of Science and Technology for Education & Research (CLUSTER)	Stephan	Morgenthaler
ETH Zentrum - Physikalische Chemie	Richard	Ernst
EURAB- European Research Advisory Board	Helga	Nowotny
European Physical Society	Martin.C.E	Huber
European Society for Applied Physical Chemistry	Erwin	Marti
European Union of Science Journalists' Associations	Werner	Hadorn
European University Association	Eric	Froment
IBM Research Laboratory	Heinrich	Rohrer
Society in Science:The Branco Weiss Fellowship	Helga	Nowotny
Swiss National Science Foundation	Chairman/	President
Cyprus Research Foundation	Kostas	Kadis
Ministry of Education and Culture	Pefkios	Georgiades
Planning Bureau Ministry of Finance	Costas	Iacovou
University of Cyprus	Stavros	Zenios
ICASE - (INTERNATIONAL COUNCIL OF ASSOCIATIONS FOR SCIENCE EDUCATION)	Jack B.	Holbrook
Academy of Sciences of the Czech Republic	Helena	Illnerová
Grant Agency of the Czech Republic (GACR)	Josef	Syka
Dept. of Antiviral Research, BAYER AG	Helga	Rübsamen-Waigmann
Dept. of Research Policy DaimlerChrysler AG	Horst	Soboll
EIROforum Coordination Group	Iain	Mattaj
EMBL - European Molecular Biology Laboratory	Fotis C.	Kafatos
EMBO - European Molecular Biology Organization	Frank	Gannon
European Life Sciences Forum (ELSF)	Luc	Van Dyck
Hermann von Helmholtz Association of National Research Centres	Chairman/	President

Max Planck Society	Peter	Gruss
Max-Planck Institut für Biochemie	Robert	Huber
Max-Planck Institut fur Biophysik. Chemie	Dr. Hartmut	Michel
Max-Planck Institut für Chemie	Paul	Crutzen
Membrane Biophysics Dept. Max-Planck-Institut für Biophysikalische Chemie	Erwin	Neher
Trade Promotion, German Confederation of Skilled Crafts and Small Business	Rainer	Neumann
Union of the German Academies of Sciences and Humanities	Chairman/	President
Wissenschaftsgemeinschaft Gottfried Wilhelm Leibniz (WGL)	Hans-Olaf	Henkel
Ständigen Konferenz der Kultusminister der Länder in der Bundesrepublik Deutschland	Ute	Erdsiek-Rave
Hochschulrektorenkonferenz	Chairman/	President
Verein Deutscher Ingenieure	Chairman/	President
Verband der Chemischen Industrie	Chairman/	President
Fraunhofer Gesellschaft	Hans-Jörg	Bullinger
VDI/VDE-Technologiezentrum Informationstechnik GmbH	Chairman/	President
Deutsche Forschungsgemeinschaft	Beate	Scholz
Geschäftsstelle des Wissenschaftsrates	Wolfgang	Rohe
DESY (Deutsches Elektronen-Synchrotron)	Dr. Albrecht	Wagner
Bayerische Akademie der Wissenschaften	H.	Nöth
European Southern Observatory	Catherine	Cesarsky
Association of Danish Business Economists	Povl	Tiedemann
Dept. of Psychology University of Copenhagen	Gretty	Mirdal
ECIU - European Consortium of Innovative Universities	Andrew	Hamnett
EFB-European Federation of Biotechnology	Boerge	Diderichsen
European Association Deans of Sciences	Henrik	Jeppesen
European Consortium of Innovative Universities (ECIU)	Sven	Caspersen
R&D Division Haldor Topsoe A/S	Jens	Rostrup-Nielsen
Royal Danish Academy of Sciences and Letters	Chairman/	President
The Danish Research Agency	Jens Morten	Hansen
Dansk Industri.	Anne-Marie	Levy
Dansk Arbejdsgiverforeningein	Mette	Ringsted
ATV	Chairman/	President
IDA - Ingeniørforeningen i Danmark	Jan	Holmegaard Jensen
Handel, Transport og Serviceerhvervene	Mogens	Findalen
Dansk Metal	Per H.	Madsen
Rektorkollegiet (Danish Rector's Conference)	Linda	Nielsen
FNU-formand	Niels O.	Andersen
AC (Akademikernes Centralorganisation) Danish Confederation of Professional Associations	Käthe	Munk Ryom
Center for Science Education	Sebastian	Horst
Niels Bohr Institute for Astronomy, Physics and Geophysics	Niels O.	Andersen
Experimentarium	Asger	Høeg
Estonian Academy of Sciences	Chairman/	President
Estonian Science Foundation	Chairman/	President
National Hellenic Research Foundation (NHRF)	P.	Papagiannakopoulos
New Investments INTRACOM	Yannis V.	Tzavaras

Research Center for Greek & Roman Antiquity National HellenicResearch Foundation (NHRF)	Miltiades	Hatzopoulos
Council for Scientific Research	Emilio	Lora-Tamayo
EUROHORCS-European Union Research Organisations Heads Of Research Councils	R.	Tarrach
European Institute for the Media	Joan	Majó I Cruzate
Fondacion Cotec para la Innovacion Tecnológica	Juan	Mulet Meliá
University of Barcelona Dep. d'ECM Fac. de Física	Rolf	Tarrach
Fundación Española para la Ciencia y la Tecnología	Arturo	Garcia Arroyo
Conférence des Grandes Ecoles (CGE)	Chairman	President
AFAS, Association Française pour l’Avancement des Sciences	Pascal	Colombani
Association des professeurs de biologie et géologie (APBG)	Chairman	President
Association des professeurs de mathématiques de l'enseignement public - (APMEP)	Chairman	President
ASTS, Association Science Technologie Société	Jean	Rosmorduc
Atomic Energy Commission	Chairman	President
CIRASTI	Antoine	Hervé
CNRS - Présidence	Gérard	Mégie
Committee of R&D in European Shipbuilding (COREDES)	Patrick	Person
EIRMA - European Industrial Management Research Association	Andrew	Dearing
EPS-European Physical Society	David	Lee
ERCIM - European Research Consortium for Informatics and Mathematics	Jean-Eric	Pin
ESA - European Space Agency	Jean-Jacques	Dordain
European Association of Remote Sensing Laboratories (EARSeL)	Eberhard	Parlow
European Science Foundation (ESF)	Enric	Banda
European Synchrotron Radiation Facility	Bill	Stirling
European Technical Missions Suez-Lyonnaise des Eaux	Elisabeth	Jasulké
EUROSCIENCE-European Association for the Promotion of Science and Technology	J.P.	Connerade
EUROSPACE - Association of European Space Industry	Pascale	Sourisse
EUTELSAT S.A.	Giuliano	Berretta
Fédération Européenne des PME de Haute Technologie	Emmanuel	Leprince
Femmes et mathématiques	Véronique	Slovacek-Chauveau
Femmes et sciences	Chairman	President
Industrial, Research & Technology Dept. EADS	Brigitte	Serrault
Inspection Générale de l’Education Nationale	Dominique	Borne
MURS, Mouvement Universel de la Responsabilité Scientifique	Chairman	President
National Institute for Health and Medical Research	Chairman	President
Research Institute for the Exploitation of the Sea	Chairman	President
Société de mathématiques appliquées et industrielles (SMAI)	Chairman	President
Société Française de Chimie	François	Mathey
Société Française de Physique	Edouard	Brezin
Société mathématique de France (SMF)	Chairman/	President
Union des physiciens (UdP), association des professeurs de physique et de chimie	Madeleine	Sonneville
Union des professeurs de sciences et techniques industrielles (UPSTI)	Chairman/	President

Union des professeurs de spéciale (UPS)	Chairman/	President
Université de Strasbourg - Inst. Le Bel-Labo. Chimie Supramol	Jean-Marie	Lehn
Musée des Arts et Métiers	Daniel	Thoulouze
Cité des Sciences et de l'Industrie	Jean-François	Hébert
Palais de la Découverte	Jean	Audouze
Musée d' Histoire Naturelle	Bertrand-Pierre	Galey
Académie des Sciences	Jean	Dercourt
Académie des Technologies	Jean-Claude	Lehmann
Euro-CASE (European Academies of Technology Association)	Pierre	Fillet
INSERM, (Institut National de la Santé et de la Recherche Médicale)	Christian	Brechot
INRA Institut National de la Recherche Agronomique	Bertrand	Hervieu
IRD (Institut de Recherches en Développement)	Jean-François	Girard
INRP (Institut National de Recherche Pédagogique)	André	Legrand
Institut Laue-Langevin	Colin	Carlile
ERCIM OFFICE	Jean-Eric	Pin
Academy of Finland	Reijo	Vihko
Delegation of the Finnish Academy of Sciences and Letters	Chairman/	President
European Association of Science Editors	Georgianna	Oja
Technology Strategy Nokia Corporation	Juhani	Kuusi
Federation of Finnish Learned Societies	Ilkka	Niiniluoto
Hungarian Scientific Research Fund	Chairman	President
Hungarian Academy of Sciences	Norbert	KROÓ
Associazione Piccole e Medie Industrie (Varese)	Enrico	Ottolini
Centro Ricerche Milano Bracco Imaging S.p.A.	Fulvio	Uggeri
Dept. of Physics University of Florence	Paolo	Blasi
European Association of Remote Sensing Companies (EARSC**)**	Marcello	Ricottilli
National Institute for Nuclear Physics	Chairman	President
National Institute for the Physics of Matter	Manuela	Arata
National Research Council	Chairman/	President
Dept. of Immunology Weizmann Institute of Science	Ruth	Arnon
Dept. of Mechanical Engineering University College Dublin	Gerry	Byrne
Enterprise Ireland	Feargal	Ó Móráin
Health Research Board (HRB)	Chairman/	President
Royal Irish Academy	Chairman/	President
Trinity College	Jane	Grimson
Icelandic Research Council	Chairman/	President
The Netherlands House for Science and Technology (NEST)	Cees	Vis
Association of European S&T Transfer Professionals	Paul	van Grevenstein
Dept. of Medical Genetics University of Groningen	Charles	Buys
Dr. Martinus Veltman	Martinus	Veltman
Farm Animal Industrial Platform (FAIP)	Anne-Marie	Neeteson

Netherlands Organisation for Applied Scientific Research (TNO)	Jan Alexander	Dekker
Netherlands Organisation for Scientific Research	Peter	Nijkamp
R&D and Technology Dept. DSM Fine Chemicals	Ellen	De Brabander-Van den Berg
Royal Netherlands Academy of Arts and Sciences	Chairman/	President
The National Institute for Nuclear Physics and High Energy Physics	Chairman/	President
University of Maastricht	Luc	Soete
Stichting Weten	Chairman/	President
Museon	Arjan	Agema
Dept. of Physiology Faculty of Medicine University of Oslo	Lars	WallØe
Norsk Hydro ASA	Ragnhild	Sohlberg
Norwegian Academy of Science and Letters		
Research Council of Norway	Kari	Kveseth
Norges forskningsråd	Chairman/	President
Nasjonalt senter for matematikk i opplæringen	Chairman/	President
Voksenopplæringsinstituttet (VOX)	Chairman/	President
Læringssenteret	Chairman/	President
Universitets- og høgskolerådet (Norwegian Council for Higher Education)	Lars	Nerdrum
Nordisk Forskerutdanningsakademi (NorFA)	Chairman/	President
ABM-utvikling - Statens senter for arkiv, bibliotek og museum	Chairman/	President
Utdannings- og forskningsdepartementet	Karen	Nossum Bie
NIFU - Norwegian Institute for Studies in Research and Higher Education	Lars	Nerdrum
ESERA - (European Science Education Research Association)	Doris	Jorde
IOSTE - (International Organization for Science and Technology Education)	Svein	Sjoberg
Agência Nacional para a Cultura Científica e Tecnológica	Rosália	Vargas
Associação Empresarial de Portugal	Ângelo	Ludgero da Silva Marques
Associação Industrial Portuguesa	Jorge	Rocha de Matos
Comissão Parlamentar de Educação, Ciência e Cultura Assembleia da República	Pedro	Duarte
Confederação da Indústria Portuguesa	Francisco	Bello Van-Zeller
Confederação do Comércio e Serviços de Portugal	Vasco Manuel	Sousa da Gama
Confederação do Turismo Português Palácio Pancas Palha	Atílio	Jorge Forte
Confederação dos Agricultores de Portugal	João Pedro Gorjão	Cyrillo Machado
Confederação Geral dos Trabalhadores Portugueses	Manuel	Carvalho da Silva
Conselho Coordenador dos Institutos Superiores Politécnicos Instituto Politécnico do Porto	Luís	Santos Soares
Conselho de Reitores das Universidades Portuguesas Universidade do Algarve	Adriano	Lopes Gomes Pimpão
Conselho dos Laboratórios Associados Instituto de Sistemas e Robótica Instituto Superior Técnico	João	Sentieiro
Conselho Económico e Social	Alfredo	Bruto da Costa

Conselho Nacional de Educação	Manuel Carlos	Lopes Porto
Dept. of Social & Org. Psychology Instituto Superior de Ciencias do Trabalho e de Emresa (ISCTE)	Lígia	Amancio
FEBS - Federation of European Biochemical Societies	Claudina	Rodrigues-Pousada
Federação Nacional de Professores	Paulo	Sucena
Federação Portuguesa das Associações e Sociedades Cientificas	Mário	Ruivo
Foundation for Science and Technology	Fernando R.	Ribeiro
Gabinete de Relações Internacionais da Ciência e do Ensino Superior - GRICES	Chairman/	President
Laboratório Nacional de Engenharia Civil (LNEC)	Carlos	Campos Morais
Lisbon Academy of Science	Chairman/	President
Sindicato Nacional do Ensino Superior	Luís	Moutinho
União Geral de Trabalhadores	João António	Gomes Proença
Central Institute for Labour Protection	Danuta	Koradecka
Polish Academy of Sciences	Andrzej B.	Legocki
AB Volvo	Arne	Wittlöv
Dept. of Plant Physiology University of Umeå	Gunnar	Öquist
Council for Planning and Coordination of Research	Chairman/	President
Natural Science Research Council	Chairman/	President
Royal Academy of Letters, History and Antiquities	Anders	Jeffner
Royal Academy of Sciences	Gunnar	Öquist
Swedish Council for Research in the Humanities and Social Sciences	Chairman/	President
Swedish Council for Social Research	Chairman/	President
Swedish Research Council for Engineering Sciences	Kåre	Bremer
National Centre for School Technology Education (CETIS)	Thomas	Ginner
Nationellt resurscentrum för biologi och bioteknik	Christina	Polgren
Nationellt resurscentrum för fysik	Chairman/	President
Kemilärarnas resurscentrum	Chairman/	President
Nationellt Centrum för matematikutbildning	Chairman/	President
Landsorganisationen i Sverige	Chairman/	President
TCO (Swedish Confederation of Professional Employees)	Sture	Nordh
Teknikes Hus	Lena	Embertsén
Slovenian Science Foundation	Chairman/	President
Scientific and Technical Research Council of Turkey	Chairman/	President
AIRTO - Association of Independent Research and Technology Organisations	Brian Blunden	Obe
Association of British Science Writers	Chairman/	President
Biotechnology and Biological Sciences Research Council (BBSRC)	Chairman/	President
British Association for the Advancement of Science the BA	Chairman/	President
Cambridge Philosophical Society Scientific Periodicals Library Arts School	T.M.	Cox
Confederation of British Industry (CBI)	Chairman/	President
Dept. of Science Policy & Sc. Affairs - Europe Sandwich Laboratories, Pfizer Global R&D	Gill	Samuels
Economic and Social Research Council (ESRC)	Chairman/	President

Engineering and Physical Sciences Research Council (EPSRC)	John	O'Reilly
Engineering Council	Chairman/	President
Engineering Technology Board	Sa'ad	Medhat
European Mathematical Society	John	Kingman
European Network of Science Communication Teachers Department of Science and Technology Studies University College London	Steven	Miller
European Sociological Association	Yasemin	Soysal
FECS - Federation of European Cancer Societies	William J.	Gullick
Gatsby Charitable Foundation	Chairman/	President
Geologists' Association	Chairman/	President
Higher Funding Council for England (HEFCE)	Howard	Newby
Imperial Coll. Of Science - Dpt Chemistry	George	Porter
Institute of Biology	Chairman/	President
Institute of Physics	Chairman/	President
Institution of Chemical Engineers	Louise	Robinson
Institution of Electrical Engineers	Graham	Paterson
League of European Research-intensive Universities (LERU)	Colin	Lucas
London Mathematical Society	Chairman/	President
Medical Research Council MRC Centre	George	Radda
National Center for Initital Teacher Training in Primary School Science School of Education University of Leicester	Tina	Jarvis
National Centre for Biotechnology Education School of Food Biosciences The University of Reading	Chairman/	President
Natural Environment Research Council (NERC)	Chairman/	President
Natural History Museum	Chairman/	President
Particle Physics & Astronomy Research Council	Ian	Halliday
Royal Academy of Engineering	Alec	Broers
Royal Botanic Gardens	Chairman/	President
Royal Institution	Susan	Greenfield
Royal Society of Chemistry	Tony	Ashmore
Royal Society of Edinburgh	Chairman/	President
School of Engineering University of Birmingham	Graham	Davies
Science Museum	Chairman/	President
Science Museum Library	Chairman/	President
Science, Enginneering, Technology and Mathematics Network	Chairman/	President
Standing Conference on Schools Science & Technology	Chairman/	President
The Association for Science Education	Chairman/	President
The British Academy	Nicholas	Mann
The Nuffield Foundation	Anthony	Tomei

The Royal Society	Julia	Higgins
The Science Council	Chairman/	President
Wellcome Centre for Medical Science	Chairman/	President
The Wellcome Trust	Mark J.	Walport
ProfNet	Dan	Forbush
School of Chemistry and Biochemistry Georgia Institute of Technology	Jean-Luc	Bredas
The Rockefeller University	Christian	De Duve