part of my business, the telecommunications one, there have been many examples of biomedical instrumentation which have been developed by physicists. I have in mind not only the glamourous and expensive ones (like NMR imaging), but also the many small and simple instruments which have exploited the possibilities of optical fibres, for example. Such instruments can be developed without expensive subsidies in modestly equipped laboratories. Here small teams are needed, much smaller than the teams which developed semiconductor technology, but still the principle of teamwork remains the same.

Disciplined Interactions

Academics do not fit easily into this brave new world. Teachers at all levels have very broad responsibilities associated with being surrogate parents to hundreds of young people. Most of these young people are not going to be involved in manufacturing, even though the level of manufacturing determines the overall level of prosperity of each country. Some economists have suggested that in 20 or 30 years a kind of equilibrium will develop in manufacturing capacities around the world, as the economies of countries that are now underdeveloped mature. In such a technologically equilibrated world only 10% of each country's population would be engaged in manufacturing. For presently industrialized countries, this picture has drastic implications. In the US at present about 15% of our population is engaged in manufacturing, so that if this picture is correct, the fraction will drop by 1/3. For Germany, where the current figure is 32%, the implications are even more drastic. There the fraction could drop by 70%.

We are thus faced with a paradox which is of great importance to scientists. On the one hand each country's prosperity will depend on success in manufacturing. However, if only 10% of revenues comes from this sector, and more than half of the population obtains advanced education of some kind, then scientists will be spending 80 or 90% of their time teaching basic science to students who will have no direct applications of this knowledge. Somehow these two points of view must eventually be reconciled.

There is no automatic means or recipe for reconciling manufacturing and educational needs. More than ever, responsible and active government involvement is needed to bring the two cultures together. On the whole Japan seems to have achieved the greatest degree of success in this area. It has generally relied on joint consultations between representatives from universities, industries and government topic selection in a way that is academically feasible and industrially rewarding. This requires, however, a great deal of discipline among academics. In the United States we have not had much of this, as the SSC demonstrated.

The problem of disciplined academic-industrial-governmental interactions is exacerbated by the fact that one school of thought argues that education in applied science should not or cannot be carried out in universities, but that such training should be done in industry itself. My own feeling is that most of the industrial efforts at mentoring which I have observed have been amateurish to the point of absurdity. Graduate schools perform invaluable services by training large groups of young scientists and grading them according to abilities and interests - tasks which cannot be carried out in industry. I have witnessed some of the disasters that can occur when industrial mentors are overcome by virgin pedagogical enthusiasm and try to train technicians to do the jobs of scientists. For a very few individual cases successes are possible, but those exceptions are rare.

When we talk of disciplined academic - industrial - governmental relations we mean just that. I believe that much of the disappointment with the results of government-supported research stems primarily from absence of this discipline. It is true that academics guard their independence fiercely, but then no one forces them to accept government funding. It is very tempting to simply divide available funds equally, or give them to interest groups which are largest and can afford to dedicate the largest amount of time to lobbying. This is why large science has received so much in the past. But if one simply asks how many people in industry are doing similar work, and makes a first-order correction for growth, most of these problems can be avoided. It is not too hard to recognize Gresham's law in action, and to identify fields where the pressure is greatest to create government-supported positions for recent graduates who would otherwise have great difficulty finding employment.

Europe Needs Special Measures

J. Bessa Sousa from the University of Porto argues that the European situation must be placed in the correct context.


J. Bessa Sousa

In spite of Europe's decline in external competitiveness, it has (surprisingly) maintained social welfare growth for many years. But alarming signals are emerging nowadays, notably a large unemployment rate, almost stagnant economies and increasing difficulties in the process of European integration. High salaries combined with low rates of industrial production and innovation are different views of the same problem.

It will be difficult to improve consistently the quality and cultural aspects of life in Europe without a major internal restructuring process, for economic integration alone seems insufficient to promote the necessary global transformation. When planning for the 21st century, Europe should select the most promising emerging areas of science and technology and promote priority research and concerted actions in them. But it will be erroneous to assume that this will be enough to put Europe in the front row insofar as the competitive exploitation of new technologies.

A critical assessment should be made of the actual strengths and limitations of Europe's science and technology before embarking on a concerted strategic plan for the future. The present shortcomings and limitations, if not properly corrected, will constitute a very shaky basis for implementing any strategic plan.

For example, science and technology may not be adequately mature in Europe as a whole. In other words, they may not be adequately developed and implemented in the various regions and countries. For one can ask whether Europe is taking full advantage of all of its human resources and research capacities, and indeed whether it can compete with scientifically more homogeneous and integrated countries such as Japan or USA.

At present, only a few European countries participate in true sense in meaningful international competition, and only a very few companies are involved. Europe must promote a more balanced participation, with an improved distribution of its scientific and technological expertise, and of the benefits resulting from the industrial applications. Without a more participative global effort it will be difficult to cope with the competition (and faster development) coming from Asia and North America.

Therefore, besides economic integration Europe needs an integration programme in science, technology and industry aimed at a more homogeneous distribution of medium-size research facilities and of technological expertise and skills, and the creation of a real partnership in developing and setting up the new industries which are needed. This programme should also lead to a proper integration of the

European Union's peripheral countries and its neighbours to the east so as to increase significantly Europe's overall strength and potential to adjust to world competition.

The remarks by J.C. Phillips on the value and effectiveness of small-scale science as opposed to large-scale projects must be endorsed. Europe should build efficient networks of research groups and laboratory facilities, taking full advantage of the richness and diversity existing in the different countries. Recent European Union networking and mobility programmes should be encouraged. In parallel, a programme could be launched to create a network of strategic medium-size research facilities in the various European regions, with adequate interfaces with industry and conditions that promote an efficient transfer of scientific knowledge to new applications.

I also support the need to introduce new approaches in teaching and training science at the university level. In particular, we must learn how to integrate high-level science with technologically oriented knowledge in order to formulate "science with a purpose". An overly academic and removed science, although very formative and of universal validity, is generally ineffective if it is not complemented by (simultaneous) information on the applied aspects of science and the basic principles behind modern technology. Students should also be trained in the use of science for solving concrete problems, in an open environment and through interaction with non-academic people. As J.C. Phillips pointed out, most of industrial practice consists not of profound inventions and carefully prepared discoveries, but of quick and timely incremental steps which either enable new methods, or which control quality to stabilize and improve the yield of older makeshift methods. Here, acute awareness and mixed experience (science/technology) are crucial factors for success.

We Need the Whole of Physics

J.T. Devreese from the University of Antwerp points out the danger of trivializing parts of physics.

J.T. Devreese

The analysis by J.C. Phillips at CMD-EPS '96 of solid-state physics was certainly stimulating. But remarks such as "high-energy physics has been dead for 30 years" and a strong opposition to the SSC that were perhaps intended to enliven the discussion. They should be taken *cum maximo grano salis*. First of all, high-energy physics remains a vigorous field with some of the best minds at work. In the period referred to we have seen the discovery of the J/psi, of the W and Z bosons and of the top quark, as well as the development of the standard model of particle physics which constitutes a great step forward towards realizing the dream of unification. These achievements have not only contributed to our understanding of the "building blocks" of Nature but also shed light on the evolution of the early universe. Think of the marvellous "first three minutes" of Weinberg; the fact that the structure and dynamics of the universe is correlated with the fine details of elementary particle physics is a fundamental insight with a major cultural dimension. Furthermore, the methods of theoretical high-energy physics have been most fruitful for condensed-matter physics, notably path integrals and Feynman diagrams, and concepts such as scaling, universality and symmetry breaking have been useful in many fields of physics. The unique tool of synchrotron radiation, so dear to solid-state physicists, is a by-product of high-energy physics.

We need all of physics: the beauty of celestial mechanics, the depths of phase transitions, the excitement of understanding the hydrostatic paradox or the colour of the sky, the joy of calculating the Lamb shift or measuring the 21 cm line. It is counterproductive to minimize the significance of areas other than one's own. It is also hard to see how to attract students by trivializing the value of parts of physics. What we must convey is the richness of the entire subject and, indeed, of the whole of science.

So-called small science is indeed invaluable: the work of Müller and Bednroz on high-T_c superconductivity was realized with modest budgets, and the same is true for the Binnig-Rohrer scanning tunnellng microscope. On the other hand, detection of the quantum Hall effect was facilitated by the availability of high magnetic fields. So we should open up the full potential of both large and small science.