made in wild or laboratory animals to humans, who often have very different hormonal metabolisms. "There isn't a single chemical that doesn't have an effect," he said, but "what are these animal studies telling us?" Witorsch agreed that making such assumptions is like "shooting from the hip". "To judge *in utero* effects in rodents and try to extrapolate them to humans has to be done with caution," he said. "An observation doesn't mean that you should ban a substance and a lack of observation doesn't necessarily mean that it is safe."

For that very reason, many experts think that broad screening programmes based on animal testing, such as the EDSP, do not make much sense. "They're going to find some [chemicals] that are active and some that are inactive—so what?" Safe said, adding, "Is that the best use of taxpayer's money?" Nevertheless, the EPA has devised new testing guidelines that should address the subtleties of endocrine action better. Their new multi-generation tests investigate several endpoints relevant to reproductive performance, such as the female oestrous cycle, various parameters on sperm count and quality in parental and F_1 generations, and the age at puberty in the F_1 generation; they also include pathological tests for the impaired development of various organs. However, Witorsch remains unconvinced. "I'm not enthralled by the EDSP. ... These tests have been designed without appreciation of the complexity of the endocrine system," he said, adding, "I'm as overwhelmed with the EU approach as I am with the EDSP." Furthermore, as most of the testing and research concentrates on oestrogen and thyroid receptors, Witorsch thinks that it misses other equally important players in the endocrine system. "One of the benchmarks of naïveté is to totally ignore glucocorticoids and the physiological role of stress response," he said.

Sharpe is equally unconvinced by broad screening programmes and would rather put the focus on good epidemiology. "We need better exposure data. And that's the area where we have the weakest information," he said. Starting with chemicals for which there is genuine concern about cancer and male reproductive disorders, investigating their exposure particularly during pregnancy and then looking at their activity "would be a hell of a lot cheaper. ... It is possible that there are compounds out there that [modulate the endogenous system] and that they are very potent. But you can't find those with a

screening system." The Royal Society's working group came to the same conclusion: "The report emphasises the difficulties of making generalised assumptions based on isolated experiments and the problems of developing policy in areas in which scientific understanding is still being developed. ... In order to improve our understanding of the relationship of EDCs to health and disease, further investigation is needed."

Instead of "fishing expeditions", Witorsch thus advocates "good mechanistic research" to gain more knowledge about hormonal action and physiological pathways before making any further assumptions about potential health problems. "We can only accept at this particular stage that it is a mechanism that we have to explore more," he said. In the light of public fears—unfounded or not—it is certainly necessary to shift the debate about the human health dangers of endocrine disruptors to a more factual level. And that includes scientists. "The important thing is not to listen to what I say or what vom Saal says but to look at the facts," Safe said, "And then the question you should ask is 'is there anything?'"

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The changing identity of the scientist

As science puts on a new face, the identity of its practitioners evolves accordingly

Last year's *Science and Engineering Indicators 2002*, the US National Science Board's biennial report about science, technology and engineering in the USA, stated, "It is generally conceded that scientists and engineers have somewhat of an image problem" (US National Science Foundation, 2002, pp7-25–7-31). It further describes how a 'Draw-a-scientist' test administered to children revealed that the stereotypical images of scientists are "alive and well in the minds of children". And the

stereotype is not confined to children. A survey of general public opinion would readily find a scientist depicted as a white male, middle-aged or older, wearing a lab coat and glasses and featuring some type of facial hair. This image and various literary characters from Dr Faust and Dr Frankenstein to Dr Moreau and Dr Jekyll have contributed to a constructed and more or less unattractive vision of the scientist, often at odds with the self-image cherished by the scientists themselves. These fictional representations and the

collective imagination of the scientist are reflections of the response to the role of science and technology in the social context. Even more radically, the actual image of scientists is inseparably linked with the transmutations of science itself, of which the scientist is at the same time product and agent.

Without doubt, science has put on a new face in the past century. It has come to occupy a central role in society and now enjoys a privileged position among the knowledge-producing disciplines. As a consequence, the resources devoted to science have increased hugely. There has also been, in general, a visible shift in the way in which science is organized and in how it produces knowledge. Science has become 'big', global and complex (Price, 1971), and the emphasis has shifted from the individual scientist to collaborative work. Similarly, scientific knowledge production has become more costly, and forms of funding have subsequently changed, with industry and venture capital now providing the bulk of financial resources.

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During the past five decades this restructuring of science has also coincided with significant shifts in science policy. As early as 1945, Vannevar Bush, US President Franklin Delano Roosevelt's science advisor during World War II, published his seminal book *Science: the Endless Frontier*, in which he laid out the need for a national commitment to basic science, which he regarded as the foundation of national security. Although he fell from grace after Roosevelt's death in 1945, his book has been influential in shaping the science policy of the United States and other countries. After World War II and during the first years of the Cold War, nuclear and space research understandably received most attention and support. But with the elucidation of the structure of DNA and the genetic code, the life sciences quickly became a major focus of scientific research. Researchers from various scientific backgrounds gradually created molecular biology as an academic discipline and established international collaborations and organizations that emulated the pattern of organization in physical research (Strasser, 2003).

Since then, molecular biology has seen the rise of new trends and revolutions, such as the transformation of neurobiology, cell biology and developmental biology into molecular sciences, and now the integration of high-throughput analysis methods into the fields of proteomics and functional genomics (Kafatos, 2002).

In such a globalized scientific world, increasingly defined by new technologies, Louis Pasteur, Robert Koch or Pierre and Marie Curie would probably feel out of place. Their work was primarily conducted in isolated laboratories, but their deep scholarly attitude, dedication and surely uncommon wit helped them to achieve outstanding discoveries. These achievements, made during the first half of the twentieth century, spawned an image of the science practitioner as an exceptional person with a high social status who enjoyed distinguished respect. However, at the beginning of the twentieth century, not everyone was allowed into science. Until the end of the nineteenth century, gender restrictions as well as racial and religious discrimination kept women and minorities out of many universities. The current situation is profoundly different. Although some scientists could still lament a *de facto* gender discrimination, most of these barriers have now disappeared and the whole academic system is saturated with a growing number of practitioners. Every doubling of the population has seen a tripling in the number of scientists, and today there are more working scientists than have previously existed in the entire history of science (Price, 1971; Giddens, 1999). This has led to a 'normalization' of the scientist's status and a democratization of scientific activity, as the few prominent heroes have given way to an army of anonymous workers (Weingart, 2002).

Consequently, it is almost inconceivable to conduct research away from institutionalized establishments and isolated from other scientists. Collaboration and teamwork have become essential elements of scientific activity and have

created an interconnected community in which the individual is replaced by the collective. To use a musical metaphor, the solitude of a single instrument is replaced by the symphony of an orchestra, with each individual instrument striving towards the same goal. But this pluralism, in small groups or on a global scale, may come at the expense of the freedom and creativity of the single scientist. The enormous number of practising scientists means that not every one of them will make a magnificent discovery. "However, it is incorrect to think that social status and respect for scientists have disappeared," remarked Hannah Landecker, Professor of Anthropology at Rice University in Houston, Texas, USA. "The scientist has

never been and probably will never be a 'working class' designation.

In addition, institutions like the Nobel Prize are still in place to provide us with individual heroes." In other words, in science, as in any respectable orchestra, there will always be a couple of virtuoso soloists.

The expansion of knowledge and the number of practitioners has also forced science to enter an irreversible process of specialization. This has led to a wide differentiation of subjects, to the extent that researchers are bound to a narrow field of research and maintain only an incomplete and vague idea of neighbouring fields. It is not surprising, then, that multifaceted scholars, curious about and engaged in other disciplines, are increasingly becoming rare. "Being well-read in literature or a skilled writer or philosopher does not seem to be high on the list these days, and might not even be possible for students and young scientists trying to succeed in today's laboratories," said Landecker. "Pressure to achieve and succeed are probably directed at a different kind of eclecticism than you might have found in scientists educated earlier in the century in a liberal tradition, where they probably learned Classics and Latin and Literature. I would suspect that the eclecticism of today mostly takes the form of being interdisciplinary enough to work in new fields that combine computing and life science, or material science and biology, or necessitate a certain skill with physics in order to explore new imaging techniques, and so on." Steven Shapin, Professor of Sociology at the Science Studies Programme, University of California, San Diego, California, USA, noticed that the non-requirement of cohabitation of the two cultures of art and science for many scientists probably relies on a 'deconceptualization' of biology, in the sense that, as a discipline, "it has become extremely instrumental and technical and it has lost the more theoretical and philosophical integrative framework which it had in the past."

In addition, the very character of biological research has changed. It is no longer a descriptive science that involves collecting butterflies and giving them Latin names. Biologists now regularly intervene in nature and life by modifying the genetic structure of organisms. At the same time, biological research has gradually moved out of the purely academic realm and into the laboratories of industry. Scientists have created complex alliances between academia and industry, with the boundaries between science, politics and economics becoming increasingly indistinct (Shotter *et al.*, 2003). This development has also brought disenchantment with what is by now an almost utopian vision of scientific practice, based on the virtuous pursuit of objectivity, universalism, disinterestedness and impersonality, which R.K. Merton

idealized in the middle of World War II, when physicists and chemists were engaged in defence research (Merton, 1942).

Clearly, many academic researchers who still espouse an ethos based on meritocracy, peer review, autonomy and openness would feel uncomfortable with the norms and limits of industrial science, such as secrecy, hierarchy and control. Indeed, the object and direction of research in industrial laboratories are dictated by the corporate bodies who fund it and by the terms and expectations of their consumers and shareholders, which are often not in line with the doctrines of objectivity and impartiality of basic research. But some argue that the commercialization of research in general is becoming almost inevitable for academic research as well. Experimentation in the life sciences now relies on increasingly sophisticated and expensive materials and instruments. Research is no longer a cheap undertaking that can be done with a few simple and readily available tools that, up to the twentieth century, gentlemen scientists from wealthy families could just pay for themselves. As a result, national investments into research and development continue to grow.

Scientists have created complex alliances between academia and industry, with the boundaries between science, politics and economics becoming increasingly indistinct

Furthermore, ever since the US government provided massive funding to the Manhattan Project to build the atomic bomb, money spent on academic research has increasingly been tied to expectations. Publicly funded science in all fields is now a major investment with the aim of developing new tools to cure society's ills. Most of the money that the US government spends comes either from the US National Institutes of Health or other Departments, such as Energy, Agriculture or Defense, and is handed over to scientists with the expectation that their work will ultimately develop new solutions for problems in public health, energy or food supply, or national security. Europe is currently witnessing another incarnation of the transition from science as a purely academic enterprise to science defined by society's needs. Academic scientists argue, in line with the 'old' model of academic

research, that the European Commission (EC) should create an instrument to support basic research based only on the merits of scientific quality. The EC, in contrast, follows the 'new' model, which dictates that science ultimately should serve society, and that particular structures and controls are required to achieve this. In general, whether in Europe or in the USA, the expectations of citizens, politicians and industry gradually transform scientific research from an independent and scholarly enterprise into a service for society.

In this 'post-academic' environment (Ziman, 1998), scientists can no longer see themselves as detached from larger society but have to detach themselves from pure scientific sentiment. "Different spheres of value—scientific, commercial, ethical, political—are coming together into individual scientists' lives, particularly young ones, and they are not necessarily being equipped to think through how to make those different values go together in one coherent way of working and being," concluded Landecker. Indeed, partisans of the belief that science is independent of society need to accept the view that changes in society and science go hand in hand, and they need to recognize their co-evolution to understand these transformations (Nowotny, 2003). It is therefore crucial for scientists, as members of modern society and practitioners of scientific activity, to remain aware of them.

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