A tree full of the fruits of opportunity

A new paradigm for education, training and career paths in the natural sciences

• by *Torsten Wiesel & Enric Banda*

Since the end of the 19th Century, the education and training of scientists has proceeded along a narrow, unidirectional track, a 'pipeline' that draws in graduate students and produces new research professors within a given scientific discipline. For scientific research in a select group of nations, this traditional model has proved successful in many respects. But signs of inadequacies are increasingly apparent. Indeed, the pipeline model is failing to meet the demands imposed by the complex global, social and interdisciplinary climate of the 21st Century, and it is clear that science education and training must adapt to the developments taking place in society.

It is perhaps not coincidental that the pipeline model of science education has much in common with the legendary ivory tower. Both pipeline and tower are narrow, cylindrical structures that suggest unidirectional movement and a stony impermeability to the outside world. This image reflects the inflexible disciplinary divisions that still exist within many universities as well as the rigid definition of success for those students who enter the pipeline: to ultimately become a research professor heading a laboratory within a well-defined scientific discipline. Those who choose other exit points from the pipeline not only fail to achieve this outcome but are considered to have failed in achieving success in their careers.

While the vast majority of young people who undergo long periods of education and training in business, engineering, medicine or law can anticipate employment in their chosen field, the same cannot be said for those trained in the natural sciences, according to the traditional pipeline model. Indeed, it is common for them to spend more than ten productive years as a graduate student and then as a postdoctoral fellow without

any real prospect of obtaining a full-time academic position. This is already causing a crisis at the entry-point of the traditional scientific pipeline—since only a limited number of career options seem to be offered, this deters many bright students from studying the natural sciences.

To address these problems, the Human Frontier Science Program (HFSP) and the European Science Foundation (ESF) invited the heads of major research funding agencies from Europe, North America and Japan to Strasbourg, France, in

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November 2001, to discuss the problems associated with this traditional model of science education and training and to search for alternatives. The participants concurred that new innovative models could serve as catalysts in shaping national science education, particularly if research-funding entities collaborate effectively with ministries of education, research institutions and the private sector. The consensus from the meeting indicates a new paradigm for education and training in the natural sciences, one that would be more expansive in its goals and more attuned to the needs of both society and young scientists. This new organic paradigm visualises science training and careers as a tree with a richly ramifying, highly permeable network of roots and branches. This image better reflects the broad social base on which the natural sciences now rest, as well as the wide range of potential career

opportunities that are becoming available for scientists, some of which directly involve research whereas others may be associated with science to varying degrees in industry, schools, administration, government, the media, business and many other domains. It would seem logical to discuss the various issues as we move up the tree from the roots to the upper branches.

The role of the roots is to attract the best and brightest students and to enhance the interactions between science and the public. It is clearly through the early stages of science education in primary and secondary schools that young people are drawn most effectively into science. The goals of this stage should be to introduce the language of science and the laws underlying natural phenomena in ways that are vivid and stimulating to young minds. Moreover, science should be taught as a supreme exercise of human curiosity, imagination and accomplishment. With science literacy in many countries around 10% or even lower, there is obviously a great need for improvement at this level.

Ideally, science should be taught as a process of sustained questioning and exploration, not just the accrual of frozen facts. Funding organisations, such as the Howard Hughes Medical Institute (HHMI), The Wellcome Trust, the US National Science Foundation (NSF), the UK Medical Research Council (MRC), as well as many universities and national and local academies have shown great foresight in developing programmes to encourage this. They provide students with research experience, train teachers and educate the public through museum and science exhibits. In addition, other experimental programmes aim at creating centres that teach secondary school

students cutting-edge science using the very latest equipment.

It is encouraging to note that there is growing interest among scientists in assuming greater responsibility for developing such outreach programmes. 'If there is one lesson I have taken from this meeting,' said Wieland Huttner of the German Max Planck Society, 'it is the need for scientists to reach out to the community. I will return to my institute and encourage our researchers to interact with students in our community schools.' Indeed, his remarks highlight a major resource that could be used to bridge the gap between the culture of science and human culture at large, namely the story of science as told by scientists themselves. These stories could serve as vivid exemplars of the ways in which science draws young people from diverse backgrounds and interests into its roots and show how science's advances into the unknown continue to yield new puzzles and answers. Furthermore, the scientists' career histories would also demonstrate the many ways in which scientific training, scientific disciplines and jobs branch and interconnect. Some internet resources, such as Next Wave (<http://nextwave.sciencemag.org>), are already collecting such accounts as well as experiences from those who have used their scientific training as a route to an alternative career.

Ultimately, the aim of science education should not only be to attract the most talented and energetic young minds to science, but also to instil in citizens of all

ages and from all areas of life an appreciation of and a familiarity with scientific language, ideas and modes of investigation. As our societies are increasingly driven by technological progress, there is a growing need for citizens to be able to assess the impact of scientific advances on society.

The trunk and intermediate branches represent the education of young scientists at colleges and universities. Ideally, this part of the pathway should be structured in such a way that students receive wide exposure to various disciplines and career opportunities to map their talents within the sciences and onto a broader range of professional opportunities.

There is now widespread recognition that many scientific research paths, particularly in the life sciences, transcend

sciences, for instance, has been driven to a large degree by the availability of new tools developed in physics, chemistry, informatics and engineering. Thus, with the current convergence of the natural sciences on biology, there is a real need for scientists trained beyond the traditional disciplines.

A number of funding agencies have established model programmes to provide interdisciplinary training from different departments and to offer experiences in a variety of research venues, including industrial settings. With the growth of proteomics, genomics and other large-scale approaches, there is an increasing demand for large, interdisciplinary groups that collaboratively probe many aspects of complex biological systems. This new collaborative approach to problems in the life sciences—an approach that has long been a feature of research in the physical sciences—is already part of a small number of model programmes, such as the NSF IGERT Program and the Max Planck Society's International Research Schools, which have successfully attracted high quality students and have fostered a new interdisciplinary culture. Their success and the new paradigm for science training that emerged at the Strasbourg meeting should stimulate a dialogue that, in due time, will lead to the restructuring of science education.

The implications clearly extend beyond the academic realm to society at large. Over the past 20 years, the world has been increasingly driven by scientific and technological innovations and opportunities. Never before has there been a greater need for individuals with a strong education

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conventional disciplinary boundaries. This means that research training requires a broader didactic base and experiences beyond those a single laboratory or department can provide. Clearly, the traditional model of training based on classically defined disciplines is outmoded, even though it is still the norm at many universities. Emphasis on more than one discipline and a breakdown of department barriers would make it easier for students to be exposed to more than one scientific field and to move between them. The current revolution in the life

sciences to meet the needs of industry, business, government, administration, teaching, journalism and a host of other sectors. Consequently, there has been a concerted effort to strengthen and restructure science training programmes to provide exposure to fields outside science. Some funding agencies support programmes that include training in administration, teaching and ethics as a way of enhancing the scientific research enterprise and laying the groundwork for alternative careers. Programmes should also make sure that students have research and

training experience outside the academic environment, preferably at an early stage of their education. In addition, they should provide career mentoring and ensure that the Master of Science degree, often viewed as only a stepping-stone to a PhD, is valued in itself as a legitimate endpoint in the spectrum of formal scientific training. Universities should offer guidance on career development for students pursuing scientific careers and clearly state that there could be a number of legitimate formal educational endpoints, all of which could lead to excellent professional opportunities.

A period of postdoctoral training is an essential part of the preparation of scientists—especially those in the life sciences—before they are ready to assume independent research positions. This is therefore a critical period for broadening research experiences, learning

new techniques and skills and becoming acquainted with new scientific perspectives and approaches. It is generally during postdoctoral fellowships that young scientists have the best opportunity to prove their mettle and sow the seeds of a successful independent career. Too frequently, however, postdoctoral fellows

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are treated as highly skilled and hard-working technical assistants rather than scientific minds in training. They labour on projects where broader educational goals are largely displaced by the fulfilment of an advisor's research objectives that may not be in their best long-term interests. Moreover, the academic

mechanisms to monitor their progress are rarely accompanied by equivalent mechanisms to guide them. The development of special postdoctoral mentoring programmes by a number of institutions, such as the one at the University of Pennsylvania, will meet an important need. Funding agencies should insist that all institutions receiving support must provide the kind of mentoring and training that is outlined in a recent report from the US National Academy of Sciences.

The upper branches of the tree correspond to numerous potential endpoints of scientific training. Some of these represent outstanding scientists who have completed their postdoctoral training and risen to independent positions, leading their own research laboratories. Outside the academic setting, industry and the biotech sector have also attracted

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outstanding scientists and it is expected that, in the future, collaboration between academia and industry will be an integral part of the research community. Leading scientists also serve as government advisors or as elected members themselves or often hold important positions within governmental agencies.

Only a small proportion of students will eventually attain positions as independent investigators or scientific group leaders. Organisational policies in many countries exacerbate this problem—countries that structure their scientific enterprise around a large group that is financially and scientifically dependent on a single departmental leader produce fewer independent investigators. Thus, even the best and the brightest young scientists—those who successfully complete postdoctoral fellowships or their equivalent and who demonstrate resourcefulness, technical skill, intellectual acuity, originality and imagination—find it difficult to obtain independent positions. Not only does this waste innovative talent, but it also fuels the ‘brain drain’, causing a nation’s vital talent to emigrate to other countries that provide them with better opportunities to determine their own research paths.

This problem is generally recognised. Indeed, all of the countries represented at

the Strasbourg meeting have begun to address this issue by establishing innovative programmes to facilitate independence for their most promising young investigators. Often coupled with a period of training in a foreign country before repatriation, these awards offer the newly established young investigators the opportunity to not only learn new skills and explore new areas of science but also to establish important personal contacts needed to forge transnational collaborations. Such programmes, instigated for instance by the Markey Trust, the Max Planck Society, the European Molecular Biology Laboratory and the Volkswagen Stiftung, have produced a generation

But successful leadership of a research team depends not only on scientific prowess but also on the ability to manage substantial financial and human resources—running such an enterprise requires many of the same management skills needed to run a small company. The meeting participants thus called for efforts to provide young scientists with appropriate management training, preferably beginning in the pre-doctoral phase and continuing throughout a scientist’s education. In addition, scientists at all levels should receive training in communication skills to ensure that they can convey their findings effectively to the broader scientific community, political leaders and the general public.

Advancement in academic research is based on a number of measures, including the number of publications, grants and other awards. While these measures are quantifiable, they may fail to fully assess the quality and originality of scientific thought, which is the most important gauge of research achievement. Moreover, measures of achievement may discriminate against family life and primary caregivers, particularly women. It is important to ensure that the criteria utilised by institutions for promotions and awarding prizes stress excellence and originality, not merely the number of publications achieved. Through funding guidelines, agencies can also encourage institutions to develop a family-friendly infrastructure to attract, retain and support their best talent.

Teaching is important in all phases of scientific career development and is a key component of life within a university community. However, in many countries, the best scientists are often associated with research institutions where they may not come into contact with students,

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of leading independent investigators throughout Europe and North America and are now being replicated in other countries. In addition, in countries where administrative structures limit new positions and constrict mobility, new programmes, such as L’Avenir in France, have been designed to bypass these barriers.

particularly those at the beginning of their university training. The consequence of such dissociation is that students may not be exposed to the best science. A solution is exemplified by HHMI, whose investigators are provided with salaries and research support but remain part of the university environment, thus ensuring that

students have contact with the best scientists.

Science, by its very nature, is a global affair. Scientists from different cultures and backgrounds pose different questions and use different approaches to answer them. Creativity often arises at the intersection between disciplines and cultures, and many important scientific advances have arisen from young scientists who are open to new ideas being challenged in a new environment. Programmes such as HFSP, the EMBO fellowships, the Japan Society for the Promotion of Science and the European Commission's Marie Curie Fellowship Program facilitate international exchange for students early in their research careers. For those who are establishing their own independent groups, the HFSP, The Wellcome Trust, the EU Framework Programme, the DFG and most of the other participating agencies have developed programmes to promote repatriation and international collaborations by providing opportunities

for young scientists who have spent time abroad. These reinsertion programmes can serve as an important driving force in increasing institutional flexibility. The participants of the Strasbourg meeting thus emphasised the need for international mobility of scientists and the value of international exchange. They particularly called for opportunities for pre-doctoral students to undertake short visits to study abroad, as when students become mobile early in their training they are more likely to have a broad range of contacts and to continue international interactions.

Many of the recommendations emerging from the meeting are at various stages of implementation in the participating countries. By agreeing on basic principles and a concerted set of actions and by working together rather than in isolation, common goals are more likely to be achieved. As Mary Clutter of the NSF so nicely summarised: 'How much more powerful, if we joined forces.'

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This article is an abridged and edited version of *Toward a New Paradigm for Education, Training and Career Paths in the Natural Sciences*, compiled by Danuta Krotoski and Geoffrey Montgomery and published by HFSP and ESF. The full text of the position paper can be found at: http://www.hfsp.org/pubs/Position_Papers/funders.htm.

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