As authorship is often the most important criterion by which selection committees decide on the careers of scientists, radical or sweeping changes in the present system are unlikely. But change might come if these committees used a different ranking system; indeed, it would probably even simplify their work if they adopted a more quantitative method to assess authorship and made the award system more transparent. But authorship is not everything. "My opinion is and has been that one needs to look at the candidate in detail and beyond authorship," commented Mattaj. "You cannot measure someone's contribution by looking at a paper, at what they have done. You also need to look at the candidates themselves, interview them and talk to them in detail, to have a good idea of what really their capabilities and contributions are."

Regardless of any changes or adaptations, authorship will remain an intricate issue in science because of the logic of its reward system, which is distant from that of intellectual property law (Biagioli M (2003) in *Scientific Authorship. Credit and Intellectual Property in Science*. Routledge, New York, USA). The scientific community prides itself on the fact that its work is based on an ethos of meritocracy, impartiality and integrity. Its actions and conduct are generally, and particularly in the case of scientific authorship and accreditation, regulated by an acknowledged system of conduct and by individual honesty, which is separate from the legal jurisdiction that is normal for most other forms of copyright. Furthermore, there are no sanctions or other forms of punishment for fraudulent authors beyond firing them or denying them access to funding. The harshest measures are forms of exile or ostracism from the scientific community, but they carry no tangible legal consequences. This generally acknowledged integrity is a widely admired aspect of the scientific community, but it also explains why there is little perceived urgency to introduce a unified authorship system or create an external monitoring body to avoid abuses. "I feel one needs nothing short of a 'paradigm shift' in how authorship is viewed and 'felt' in order to be able to distance one from the current lack of a system and appreciate what quantitative systems could improve upon," concluded Verhagen.

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Waiter, there's a nanobot in my martini!

As nanotechnology gives birth to nanobiotechnology, definitions and perceptions are at risk of becoming mixed into an exotic cocktail

Barely a week passes these days without another report concerning nanotechnology and another reinforcement of the call for a moratorium on it. And, as if biotechnology had not suffered enough public scorn already, nanobiotechnology will surely attract even more. Nanotechnology itself is hard to define or communicate, so will the scientific community be able to convey what is behind nanobiotechnology before promising applications go sour in the public domain?

> But in these times of increasing scrutiny of science and technology, surely society and scientists should be grateful when someone raises a warning flag before a real public-relations disaster happens…

For a start, it might help to have a standard definition of nanotechnology, but that in itself is a problem. Although to scientists its meaning might be intuitively clear, there are many other versions floating around. To an intellectual commenting on a possible doomsday scenario, nanotechnology is synonymous with autonomous self-replicating nanomachines overrunning the planet. To a synthetic chemist, it is merely the modern term used to describe some by now ubiquitous synthesis. And a technology firm might use the word simply to spice up its latest advertising pitch. More worryingly, to a non-governmental organization (NGO), nanotechnology could be anything that involves phenomena at the atomic or molecular level.

Now, it should be possible to define nanobiotechnology, or at least some of its applications (see sidebar). How about "the manipulation of DNA at the nanometre scale?" If this sounds a bit like genetic modification all over again, it is no coincidence. It has the same critics. But in these times of increasing scrutiny of science and technology, surely society and scientists should be grateful when someone raises a warning flag before a real public-relations disaster happens, as was the case with genetically modified (GM) food. And this, after all, is the aim of the Action Group on Erosion, Technology and Concentration (ETC; www.etcgroup.org): to subject nanotechnology to a moratorium in order to develop international regulations that allow its development in a controlled manner. Otherwise, the ETC fears, this potentially useful technology could suffer a public backlash similar to that seen in the GM debate.

The problem with nanotechnology, as identified by the ETC, starts with the fact that what chemists thought of as the mere scaling down of an existing process or entity with known physical or chemical properties, is, in some cases, associated with the emergence of new properties that are not seen in the bulk material. The contention is that a new kind of regulatory framework is therefore necessary, over and above normal safety testing. Admittedly, 'buckyballs' and nanotubes are different from plain graphite, and new research even suggests that buckyballs can cause brain damage in fish (Feder BJ (2004) Health concerns in nanotechnology. *New York Times*, 29 March). However, many non-nanotechnology substances do that too, and the lead researcher, Eva Oberdörster, an environmental toxicologist at the Southern Methodist University (Dallas, TX, USA), does not think that a nanotechnology moratorium should be imposed. Another controversial case, which is frequently cited by the ETC, is that of SoilSET™—an organic–inorganic composite, which, when wetted, catalytically

binds existing soil particles to form a crust over erosion-prone land. The ire of the ETC was raised when this product was used for the first time in bulk to protect land that had been ravaged by forest fires in California. Ironically, the company that produces SoilSET™ (Sequoia Pacific Research Company, Draper, UT, USA), while defending itself with the claim that its product is based on traditional chemistry, is keen to use the word 'nanotechnology' in its advertising, thereby shooting itself in the foot.

The realization by the nanotechnology industry that the prefix 'nano' is increasingly attracting negative public attention was visible last September at Nanofair 2003 in St Gallen, Switzerland. Many companies pulled out of the event, fearing bad publicity. As Wolfgang Heckl, chief spokesman of the Center of Competence in Nano-Scale Analysis in Munich, Germany, and winner of the Deutsche Forschungsgemeinschaft (DFG) Communicator Prize 2002, noted, "it matters a lot to firms if nanotechnology makes it." People in the business, such as Tim Palmer, the Chief Executive Officer and President of Científica (Madrid, Spain), the world's largest supplier of nanotechnology information, have come to the conclusion that 'nanotechnology' is not a helpful term. "We need to quickly move away from the nanotechnology word and describe its applications," he said, commenting on the possible regulation of nanotechnology in general, "it's a bit like saying we're going to regulate physics… or have a moratorium on chemistry." That said, he recognizes the role of environmental groups in scrutinizing nanotechnology, and feels that if any group is underrepresented in the debate, it is not scientists but the commercial sector.

But whether something really is, or is merely marketed as, nanotechnology might be less important than the fact that chemical processes controlled at the nanometre scale have been used for 25 years—"25 years of unchecked research and development," in the words of Pat Mooney, Director of the ETC. And should it get the wrong spin, this could represent plenty of stored-up trouble. In the case of the GM food debate in Europe, public resistance was fuelled by little more than 10 years of research and development about which most of the public was unaware. Already the term "green goo", the nanobiotechnology analogue of "grey goo", has been coined, and the ETC is now grouping processes as diverse as the synthesis of viral genomes, the engineering of artificial microbes and nanobiotechnology into a new category, for ease of understanding, termed the "coming-to-life sciences". Although one might be forgiven for thinking that this is the nanotech equivalent of 'Frankenstein foods', Mooney is quick to emphasize the positive interpretation—new developments coming to the life sciences—and he certainly makes a big distinction between different kinds of nanotechnology. The more remote forms, such as self-replicating bioinorganic machines, are, he stressed, not on his 'hit list'.

However, it is obvious that the phraseology of the ETC articles, which gently ridicule nanotechnology with clever puns and plays on words, such as "Mulch ado about nothing" or "The sand witch", is designed to win the hearts of the anti-nanotech lobby. If NGOs genuinely want a constructive debate, why do they not approach the subject with the same care and consistency that they would expect from scientists? Instead, in the hands of non-scientific communicators, nanotechnology seems to be encompassing almost all research involving the study, manipulation or synthesis of molecules; that is, all of chemistry and most of modern biology. As Carlo Montemagno, Chair of Academic Affairs in Biomedical Engineering and a nanobiotechnology researcher in the California NanoSystems Institute at the University of California (Los Angeles, CA, USA), remarked humorously, "the way nanotechnology is bantered about, it includes everything from the person who mixes your martini at the bar to single-molecule scientists."

Behind the seeming lack of discrimination, NGOs are primarily worried about the health and environmental effects of nanoparticles, most of which actually result from combustion processes, not nanotechnology. However, synthetic nanoparticles are increasingly appearing in everyday products. Sun lotions with nanoparticulate titanium dioxide are one example. Nanoscale magnetic iron particles have been in development for diagnostics and drug delivery for some years now, and the US National Science Foundation boldly predicts that nanotechnology will account for one-half of all pharmaceutical sales within a decade. Meanwhile, nanotechnology researchers are busily attracting more public funding in the USA than any other single area of technology.

The fact that public money is also flowing into nanoscience and nanotechnology in Europe is a cogent reason for putting much more effort into supporting public understanding and dialogue in this area. As Heckl remarked scathingly, "we [in Germany] have a problem communicating science [even] at the level of education," continuing, "if people don't understand what a gene and atom or a molecule are, this makes them frightened of these things." According to him, more scientists must break free from peer denigration for simplifying things when communicating and must talk with the public, in public. "The organizations that fund science should also fund the communication of science, more than ever before," Heckl added. Not only that, but they would do well to perform their own risk studies to allay public fears. "Self policing is far superior to legislating [against] progress," Montemagno agreed.

SOME EXAMPLES OF NANOBIOTECHNOLOGY IN RESEARCH AND DEVELOPMENT

- Molecular imaging and studies of interactions between single biological molecules
- Self-assembling functional membranes with designed properties, such as catalysis, photoactivity, electrical activity, electrochemical and water-purifying activity
- DNA motors based on forces generated by the hybridization of complementary sequences
- Live-cell imaging of the movements of viruses, proteins, prions and drugs
- Precision techniques for transgenesis and site-directed mutagenesis
- New molecular assemblies for directing and enhancing immune reactions
- Technologies for targeted drug delivery
- Harnessing biological motors, such as muscle and other motile proteins, for mechanical or electrical energy production

And some, at least, have made a start. Quick off the mark as usual in the science and society arena, the UK is awaiting the results of a government-commissioned in-depth study of nanotechnology. Undertaken by the Royal Society (RS) and the Royal Academy of Engineering (RAE), its findings will be published in June 2004. Their web site (www.nanotech.org.uk) certainly provides a more dispassionate and more scientific account of nanotechnology than that of the ETC. However, even the RS and RAE have a difficult job defining nanoscience and nanotechnology, referring to their definitions as "draft" and adding that they might change as the project progresses; those wishing to get the latest version are best advised to visit the web site. Understandably, they preferred not to comment until the study results, which will include nanobiotechnology, are published later this year.

In the meantime, the RS has published a report on the views of the general public about nanotechnology (www.royalsoc.ac.uk/templates/press). Although most of those questioned who could give some kind of definition believed that nanotechnology would make things better in the future, this is little consolation given that the overwhelming majority did not know what it meant. Furthermore, participants drew a clear parallel with GM when considering the ethical implications of nanotechnology.

> "…the way nanotechnology is bantered about, it includes everything from the person who mixes your martini at the bar to single-molecule scientists"

The problem is not helped by the fact that an understanding of many of the applications of nanotechnology requires some background knowledge in several basic sciences. The nanotechnologies represent an area in which many scientific fields—physical, chemical and biological—meet, creating extremely fertile ground on which possible applications are recognized. Mark Welland, the recently appointed Head of the new Interdisciplinary Research Collaboration in Nanotechnology in Cambridge, UK, knows that this is the point at which possible societal impacts must be considered, which is why a social sciences fellow started work in his group in March 2004. "I wanted to feel I understood all the issues, and the only way to do that is to hire a social scientist […] so that we are in an informed position to make comments and investigate certain research areas," he said. As to the possibility of a GM-type disaster with nanotechnology, he commented, "GM and nano are two quite different beasts, but generally people see technology advancing at an ever increasing rate…"

Welland is the kind of institute director who is reached not through a barrage of intermediates, but directly on his personal phone line. The social sciences fellow was his idea, and the position comes at the expense of an extra postdoctoral scientist. To expose students and postdocs in the laboratory to the societal debate, he plans workshops, seminars and invitations to NGOs, companies and the public, reflecting that "50 years ago, scientists were much more closely tied in to societal issues; today it's good to look at these things early, and identify potential issues affecting all of our lives."

In common with most scientists, Welland does not entertain the notion of a moratorium on an area as broad as nanotechnology. Some of the most promising developments in medicine, such as magic bullet drugs, "would have to be put into the can," he declared. And although he concedes that there is research that leads from GM technologies, cloning and DNA sequencing to the making of new organisms by molecular machining, he added, "you'd find it hard to put your finger on what to legislate on [in that area]." But all this neglects the fact that the biggest use of nanotechnology for the past 20 years has been in the manufacture of something far more ubiquitous—computer chips—and few would argue for a moratorium on that. Silicon, it seems, is safe, and the nightmare of self-replicating machines is, according to Welland, far too futuristic to merit consideration now. Applications that are nearer at hand need to be concentrated on, and, echoing others, he laments Europe's history of not exploiting its own ideas. "At European level there is acute awareness of this, and hopefully Europe will be in a position not to let [nanotechnology] go offshore," he said. To its credit, the European Commission is funding a risk study on nanoparticles, NANOSAFE (www.nanogate.de), but much will depend on whether the debate can be made all-inclusive at many levels.

Welland's move to hire a social scientist will probably not set a general trend, but there is a consensus that more interdisciplinary discussion between professionals is needed. As Wolfgang Heckl put it, "two-thirds of the academic population, representing the humanities, just haven't been included in the debate." For that matter, neither have developing countries. And, if nanotechnology makes it over the hurdles of public scrutiny, it is to be hoped that it will have "the potential to diminish the gap between rich and poor nations by addressing matters specific to development," which are so important to the ETC. Perhaps even SoilSET™ could be of interest to developing countries that have dangerously denuded their forests, leaving the land to be eroded and washed into the nearest river. However, nanotechnology is also producing flexible polymers for solar cells that are reaching 10% efficiency levels, which are an important development for Third World countries with little in the way of regional electricity networks. Another area of great benefit could be drug delivery, where nanotechnology is producing nanoparticulate vehicles for pulmonary administration, and nano-encapsulation for drug delivery via the stomach. "A lot of vaccines and treatments could be administered without using a syringe," Palmer remarked, representing an extremely valuable innovation for countries with little healthcare infrastructure.

> …for the sake of all who might benefit from them, society must try to avoid the irrational stigmatization of new technologies

Naturally, for the sake of all who might benefit from them, society must try to avoid the irrational stigmatization of new technologies. But perhaps a characteristically evocative remark from Carlo Montemagno captures what is at the heart of the present debate for most people in First World Europe: "I treat biological molecules like Lego […] you can build marvellous things." Society needs, wants and appreciates marvellous things, but is it willing to accept the way in which they are built? That is what this is really about. And if Europe does not make that part of nanotechnology fully transparent and discuss it in public, it might not have the luxury to be choosy about these things, marvellous or otherwise. It could end up not making many of them.

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