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New forms of science

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Abstract

New forms of activity in science are appearing rapidly, due to the interaction of the new technologies of information with new political currents. Traditional practices, structures and assumptions in key phases of the cycle of knowledge production, including resources, persons, procedures, property, publicity, quality control and consequences have been challenged or transformed. Political activism within science has begun, as with the boycott of Elsevier; and the rigid ideas of 'scientist' or 'the paper' are dissolving. The future is highly challenging.

Keywords

Academic Spring; blogosphere; extended peer community; fetters; knowledge production cycle; pal review; post-normal science; quality control cycle; quis custodiet; rat reality show; Science 3.0; science of bads; secrecy.

Cross References

Chemical Science, History and Sociology; History of Science; Industrialization; Intellectual Property, Concepts of; Modernization and Modernity in History; Norms in Science; Physical Science, History and Sociology; Objectivity of Research, Ethical Aspects of; Peer Review and Quality Control; Renaissance; Science and Industry; Science and Law; Science and the State; Science Communication; Science, Public Engagement with; Science and Technology Studies, Experts and Expertise; Truth and Credibility in Science, Citizen Science

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Preface

It is well known that the new technologies of information are revolutionising practice in a great variety of fields, now even including the cheap manufacture of material objects. The powers of research science in very many fields are being enhanced and even transformed. Generally these changes in technical practice take place within social and conceptual structures that were inherited from previous epochs in science. They are important new developments, but not necessarily 'new forms' of science. Here we consider the practices and structures that cause surprise and concern when they are noticed, and that have their own momentum to continue rapid change. Generally they show the effects of the new technologies of information, combined with ideas and practices imported from the wider political sphere. Since this is all happening so recently and so rapidly, we have not been able to base our analysis on a body of reflective scholarly literature. Also, we assume a general familiarity with the phenomena and the potential of the new information technologies, taking insights from the standard contemporary sources while discounting their more speculative conclusions. Because of these constraints, this article will be more in the form of an analysis with examples, rather than a review and synthesis of literature. This is not a standard form for an encyclopedia, but the unusual subject matter requires it.

Historical Background

About a half-century ago there was awareness among scientists that things had changed. The transition was captured in the seminal book *Little Science, Big Science*, by Derek Price (1963), which reflected on the rapid expansion of science, particularly in the U.S.A., and its harnessing to production and war as in the Manhattan Project. Over the following decades, this new situation became the occasion for many reflections, along with new lines of debate, that developed gradually. The current situation of science is one of very rapid change. Attitudes and activities that were unthinkable only a decade ago are now well established. Few would have imagined that eminent scientists would organise a boycott of a leading scientific publisher? But that is what the leading mathematician, Timothy Gowers (2012), did to Elsevier, with the support of thousands, with the slogan "Academic Spring".

The changing self-consciousness of scientists during that previous period is a reminder that, in the socio-technical system of science, the intellectual and material aspects of the system are deeply implicated in one another. As we move, perhaps headlong, into a new set of material and the conceptual relationships, it is helpful to gain perspective by going further back than 'big science'. Since it is the means of communication that are most obviously being transformed by 'digital' media, we can recall the impact on science of printing during the Renaissance. This enabled the diffusion of knowledge in obvious ways, feeding its growth. The publication of a book enabled a practitioner to advertise his talents, and thereby to obtain the best patronage available on the market. Agricola, Birunguccio and Vesalius are great examples. Galileo exploited this technique, parlaying his *Sidereus Nuncius* first into a pay rise in Venice, and then to a coveted position as 'Chief Mathematician and Philosopher' at the Medici court back home in Florence.

By the end of the sixteenth century the great national industries of conquest, war and royal display gave employment as never before to practitioners with mathematical skills. The traditional status barriers between 'liberal' knowledge and 'mechanical' practice were lowered, for a few generations at least. Simon Stevin was a genius who worked as a practitioner but showed philosophical ambitions; while Galileo was just on the other side of the divide and determined to stay there. William Gilbert was the first to unify 'philosophy' and experimentation in his *de Magnete*; there he also rigorously reported which experiments worked and which did not. Bacon's rhetoric about 'torturing nature' became a successful practice among the 'experimental philosophers', most notably in the great English school with Boyle, Hooke and Newton. By the eighteenth century, the union of theory and practice was fully established, and philosophers in the 'highland zone' of Britain combined ideology and improvement (with profit where obtainable) to great effect.

As the powers of technology grew through the nineteenth century, scientists (who then got the title!) could study natural powers in artificially controlled situations, notably in relation to electricity and magnetism but also to both old and novel chemical substances. The cross-fertilisation of heavy industry with mission-oriented scientific research was established, first in Germany (starting with Liebig) and then elsewhere, notably in the U.S.A. in the great labs dominated by such iconic inventors as Edison and Steinmetz, along with the quasi-magical Tesla. During the same period the university system was forced to graft research onto its traditional roles of teaching and socialising the young elite. One later product of this merger was a collective amnesia among scientists and scholars about the role of such organised, industrialised research and development during the 'little science' period, a misunderstanding that led to much confusion when 'big science' arrived in full force.

In the epoch that was inaugurated by the Manhattan Project and is now just ending, science became 'industrialised' in several respects: in overall size, in scale of individual enterprises, and in its ever closer relations with industry. It also became 'incorporated' (Rose & Rose, 1969), that is involved in a variety of ways in the affairs of the state, far beyond the traditional connection with warfare. Somewhat naively, scientists believed that they were being asked to speak 'truth to power', when their clients frequently wanted 'policy-based evidence'. Traditional stable subject-specialty research has been displaced by 'Mode 2' (Gibbons et al., 1994), in which scientists are fungible units of production, to be deployed or discarded as the needs of mission-oriented projects dictate. In its relations to the broader society, the manipulations and distortions of research that are now familiar in connection with profit-making industry (such as research on tobacco, food and pharmaceuticals *inter alia*) are mirrored in the less notorious, but equally important practices of ministries and agencies.

The ‘Gemeinschaft’ research communities of yesteryear survive only on the margins, although Steven Shapin has argued that they are being re-created out of necessity in the fast-moving fields of innovative entrepreneurial science (Shapin, 2008).

Structures of Scientific Activity

Having very briefly reviewed the historical background, we can now sketch the relevant structures of scientific activity. Then we will be equipped to understand the influence of the new technologies on the new forms of scientific practice. It is now commonly appreciated that the old picture of ‘the scientist’ making a discovery and then turning it over to ‘society’ is very radically oversimplified. First, the possible motivations for engaging in, or supporting, research are varied. Aside from the traditional ‘curiosity’, there is also ‘mission-oriented’, ‘mandated’, ‘regulatory’, and (we must now add) ‘critical’ motivation. The relations with broader society, the internal social structure, and the ruling criteria of adequacy and value, all depend on such initial motivation. By appreciating the basic variety in the production systems of scientific knowledge, we can then consider the cycle of activities through which knowledge-production goes.

The initial motivation is but the first step in a multi-phased cycle. We might call this first step the ‘issue’, as that is where policy-relevant science gets its start. Next comes ‘policy’, which expresses the hoped-for solution and defines the parameters of the design of the project. This is most easily seen in research on risks; for ‘the risk’ is itself always complex, and simplifying design choices must be made on the subjects to be studied and on the nature of the hazard they experience (e.g. adults, children, pregnant mothers, and chronic or acute doses, average or peak exposure, etc.). And ‘problem’, giving greater specificity to the inquiry, perhaps stating a statistical hypothesis to be tested, comes soon after. Quite essential at this early stage are ‘resources’. Since science does not operate in an ideal universe, this issue inevitably brings in politics, in the classic sense of ‘who gets what, how and why’. Politics also enters with ‘persons’. Whenever policy is at stake, this can be quite crucial; even if scientists all have integrity, they act rather like judges, and this does not prevent them from leaning this way or that when confronted with uncertainty and value-conflicts. This step has become problematic in several ways recently, and is closely related to the new politics of science. Then come ‘procedures’, which are necessary because research is never straightforward, but is rather the study of the ‘proxies’ for the conceptual things and events that are of concern. In all such cases, there are numerous standards and conventions defining good practice, which are designed and implemented for avoiding the known pitfalls of data creation, interpretation and inference. A high-quality scientific paper contains dense descriptions of those procedures, thereby assuring its readers that its results are robust. At the core of the investigation there is 'production', where someone interacts with equipment (or respondents) to obtain the primary data, which will be the intended representatives of the proxies for the defined objects of inquiry. Out of this comes 'product', realised in an'inscription' which may function as 'paper', report, or patent application. Beyond that there is 'property', which also includes control over 'publicity'. It was once assumed that the public sharing of results was definitional of science, as opposed to the proprietary control over invention. But it has recently emerged that the publication of data is by no means universal in spite of being formally required by many funders and journals. Of course, when data are withheld it is impossible to operate Merton's norms of 'communalism' and 'organized skepticism' which had been accepted as fundamental to 'pure' science. Near the end of the cycle are the traditional 'applications' and the recently recognised 'consequences'. These are now recognised as critical to the inquiry, and will include the 'bads', or 'unintended consequences' that arise from the applications of scientific results. The relevant sciences here are almost polar-opposite in character from the traditional lab disciplines. For the problems are usually 'post-normal' (Funtowicz & Ravetz, 1993), in having high uncertainties and high decision-stakes, politicised debates over the assignment of burdens of proof, plus imbalances of prestige and of conventional institutional funding, with whistle-blowers sometimes being as important as researchers, and open conflict breaking out between pressure-groups and vested interests.

Such a cycle helps to explain the complexity and confusion that attends debates when science is involved with policy. Without a shared awareness of the different phases of the production cycle, debates can wander inconclusively through a maze of topics. Moreover, each of those phases of the production cycle has its own 'quality control cycle'. This feature establishes the true complexity of the process. For whenever there is an action conducted within an organised system, it will be subject to 'control' for its quality. This operation will include particular agents, operating particular criteria and adopting particular procedures for controlling and evaluating quality. Whenever a regulatory body comes to public notice, it will be seen that it has these elements: agents, criteria and procedures. Moreover, the control cycle itself is subject to control cycles. Lest this seem paradoxical, we recall the Latin epigram, "Quis custodiet ipsos custodes?" – who guards the guardians? Sheila Jasanoff first called attention to this phenomenon in science advice in her pioneering work *The Fifth Branch* (1990). Such an iteration is familiar in connection with the administration of justice, with a sequence of courts of appeal, right up to some highest court from which some political influence cannot be excluded. (More to our present concerns, as our companion article in this Encyclopedia argues (see Peer Review and Quality Control), quality has replaced truth as the effective guiding principle for science. The 'quis custodiet' iteration is a reminder that quality cannot be maintained by enforcement alone. It requires an ethical commitment, one that must be seen to be practiced at the top of any institution. In its absence, corruption and vacuous research are sure to follow. We have previously remarked on the paradox that the successful production of objective scientific knowledge depends critically on this subjective ethical commitment (Ravetz, 1971, Chapter 11).

Persons

We can now look at the production cycle of scientific knowledge in greater detail, identifying important points of novelty. In recent decades there has been a growing recognition that policy-relevant science is done better if the early stages, as Issues and even Problems, draw on broader experience than that of politicians, science advisors and experts. Some time ago the term 'Extended Peer Community' was coined, (Funtowicz and Ravetz, 1993) and since then, under many different names, the involvement of citizens has become increasingly accepted as desirable and useful. The obvious constitutional problems presented by these exercises in 'participation' have somehow not proved insuperable. Particularly on public health issues, broader participation in problem-definition has become established, starting with the campaigns by AIDS activists (Epstein, 1996). Such developments have diluted the original force of the very idea of 'scientists', as the sorts of persons involved in the research cycle become ever broader. In conventional scientific research, there is a long continuous tradition of amateurs making contributions, but more recently they had been relegated to the role of lower-status assistants. Such were the neglected sisters of astronomers in the past, and the numerous bird-watchers in the present. That approach to broader involvement is the least threatening to established orders, and it motivated the pioneering 'Galaxy Zoo'. In that case, the groups of amateurs even suggested topics for closer investigation. But a more active involvement is developing all the time, such as in the websites for folding of molecules, and even for solving difficult mathematical problems. In another direction, there is 'garage biology', still very small and marginal but with great potential. Now websites, such as Petridish.org (available at www.petridish.org, accessed 29.08.13) are being created to serve scientists who want to bypass the established channels for resources; although innocent in intent, such developments inevitably will affect the politics of resource distribution in science. More immediately serious is the parallel universe of the informally trained hackers of information technology (IT), including everything from pranksters and libertarians over to gangsters and State agents. As a result of all such developments, the status of ‘scientist’ is being progressively diluted; one no longer needs to have gone through the lengthy process of selection and training, culminating in a Ph.D. at the top of the cleverness pyramid, in order to be accepted as a member of a recognised knowledge-producing community. The status of ‘expert’, someone who has authority to solve particular problems on the basis of his specialised scientific training, is being eroded even more rapidly. With the growing contestation of science-policy issues (ranging from nuclear power to vaccination), along with the increasing use of crowd-sourcing for decisions, expertise is becoming a beleaguered role.

A most important recent development has been the loss of the presumption of Mertonian ‘disinterestedness’ in someone certified as a scientist. Authors of papers are now routinely required to declare any potential conflicts of interest, on the assumption that these are relevant to their claims. Also, research done with industrial support has its quality discounted, on the basis of presumed bias that is supported by surveys of outcomes (Lundh et al., 2012), to the point where some firms are abandoning public research. Since a very large proportion of ostensibly scientific research has been supported by industry and the military, this new awareness can destablise long-established patterns.

Procedures

A similar process of change, variously seen as erosion or democratisation, affects Procedures. For a long time, there was a common belief in a Scientific Method, those procedures whereby science unerringly produced the correct answers to its problems. It was the job of history of science to show that science always got it right, and of the philosophy of science to show how this was so. With the rise of uncertainty, first in theoretical physics, and then of complexity in knowledge and policy, this motivating faith gradually lost plausibility. The inability to specify a Method that is not logically fallacious has contributed to the difficulty. Popper’s philosophy of ‘falsificationism’, so valuable as a moral injunction, turned out to be vacuous for the construction of knowledge. Once scientific practice is dominated by statistics, there is no question of ‘truth’ as traditionally understood, for the results depend on counterintuitive and obscure reasonings about null hypotheses and confidence limits. Even the standard statistical techniques, applied unreflectively in all of 'normal' science, have been severely criticised, as by Ziliak & McCloskey (2008). As for models, which absorb ever more research effort in all fields, and squeeze out the more expensive and time-consuming traditional methodologies, the best that can be said is the classic line that 'all models are wrong; some are useful'. The 'quis custodiet' iterative principle applies most strongly to procedures. The products of inquiry are subjected to direct testing, however imperfect; but the testing of procedures is of an entirely different order of complexity and difficulty. It is not surprising that one author (Ioannides, 2005)) has found multiple examples of shoddy and low-grade work leading to unreliable and unworthy science. It is impossible to say how much of this depressing development is actually new; certainly, poor quality science has always been with us, as has been noted in the past (Ravetz, 1971, Chapter 10). But there does seem to be a much-heightened awareness of these problems within scientific communities; and this could simultaneously have the opposing effects of stimulating reform while also reinforcing cynicism.

Property

In the previous epoch the social relations of Property had not been changing with great rapidity; there was a steady displacement of the traditional 'public knowledge' by what we might call 'corporate know-how'. However, there has been a recent recognition of a deeply paradoxical situation in the management of intellectual property. In the new emerging technologies, notably in nanotechnology, there is a confused mixture of systems of intellectual property. Much work is done on public funds and in the public domain, while much else is proprietary. And this division is not restricted to results, but also to the ancillary information that is essential for the research. There has been a recent warning that the progress of the field is being seriously impaired by the thickets of property rights that surround the various bits of knowledge and technique that are necessary for research. Thus, right here in science we have an example of Marx's description of the replacement of one mode of production by another in the *Communist Manifesto*: "the feudal relations of property became no longer compatible with the already developed productive forces; they became so many fetters. They had to be burst asunder; they were burst asunder." We can see a sort of parallel in science, whereby the small-scale semi-independent handicraft researcher has recently been displaced by the knowledge-worker in industrialised, or 'Mode 2', science. Marx saw the boom-and-bust cycle of modern industrial capitalism as a sign of a similar deep systemic crisis for itself, and imagined that the revolutionary proletariat would soon step in.

That was not to be, at least on his time-scale. However, it is now widely recognised that in order to maintain the momentum of scientific innovation, the self-strangling hybrid system of intellectual property requires supplanting by the new social relations of production, characterised as 'open source' or 'creative commons' on the example of the IP systems of some key IT industries (Igoe and Mota, 2011; Brookes, 2012). Without indulging in rhetoric about 'bursting asunder' the fetters of the IP rights enshrined in patents, we can see that deep change is inevitable and already underway. Even Big Pharma has taken the point, as with the Gates Foundation on TB, and GlaxoSmithKline in its Tres Cantos Open Lab Foundation. (Nathan, 2012) Under these new circumstances, the 'gravediggers of (scientific) capitalism' will not be Marx's proletarians 'with nothing to lose but their chains', but rather Clay Shirky's possessors of 'cognitive surplus, spreading creativity and generosity in a connected age' of digital knowledge (2012).

Publicity

Innovation is even more rapid in the phase of Publicity, which is after all the life-blood of science and consisting of information. What is significant for the self-consciousness of science is the sudden discovery that there actually is an urgent and deeply problematic political economy of publicity. Previously accepted as the unproblematic norm with occasional deviations, publicity has rapidly become the focus of concern and even of grievance. This issue, even more than property, may become the lever whereby the idealistic ethical assumptions of 'little science' come to be seen rather like liberty in the political sphere, not to be assumed but requiring vigilance and struggle for their preservation. The distinguished mathematician invoking Tahrir Square against the publisher Elsevier may be iconic for the emerging contestations over public knowledge in science. The issue of secrecy and publicity emerged almost incidentally in the rather troubled evolution of the well-intentioned science of Global Warming. Leading scientists were affronted by demands for their data made by unqualified critical outsiders. Eventually it required Freedom of Information procedures against individuals and institutions, in the U.S.A. and U.K., to unlock data that had been produced on public funds. The critics could not be isolated and neutralised, as in previous debates (notably over BSE), as they formed an 'extended peer community' in the 'blogosphere', the most popular site enjoying both a readership in the millions and prizes for quality (see www.wattsupwiththat.com [accessed 30.08.13]). The issue of secrecy of publicly funded data became so urgent that there was an official response from the Royal Society of London, in the form of a working party chaired by Professor

Geoffrey Boulton (Royal Society Policy Centre, 2012). Its report strongly recommended procedures for insuring that such data should be public, although it did not extend its recommendations to the computer codes whereby such raw data were converted to usable information. In the ensuing discussion, it emerged that many rules for data publicity already existed, but that they were generally ignored by all parties to the publication process. The awareness of the problem soon extended from research data to those used in the regulatory process. It became realised that public regulators commonly make decisions based on secret data. In the atmosphere of mutual suspicion, the principle was invoked, "if they're hiding something, they must have something to hide". Accusations of possible malpractice by leading pharmaceutical companies, and of serious incompetence in data management by European regulators, have been made in the most authoritative quarters (Goldacre et al., 2012). It is only natural that the issues of publicity and quality should become entangled in this way. The most effective way to seize the moral high ground in a science-policy debate is to call for transparency and openness, thereby invoking the traditional norms of science combined with the modern imperatives of participatory democracy.

On another front, ethical issues in fairness to access to information have suddenly become urgent. Publication is not free, nor even particularly cheap. How are the publishers to be recompensed? The problems of cost and recompense in the digital age that had already afflicted the creative industries have suddenly arrived in science. Previous cozy arrangements whereby academic libraries subsidised publications through their subscriptions (and also provided a hefty profit), no longer go unchallenged. Also, it is suddenly realised that there are many worthy people out there who need access to nominally public information, and who cannot or even should not pay large fees for the privilege of sampling it. All that information waiting there on the Internet, or Cloud, turns out to be free only for those who are subsidised by an institutional library that can afford the fees for an extensive licence. Without membership of such a wealthy institution, the would-be researcher must produce significant payments for each item of essential information in the nominally 'public knowledge' sector, even for research to which they have contributed through their taxes. The publishers are now suddenly subjected to outrage, as academics accuse them of getting all their editorial services for free and then securing super-profits through their quasi-monopoly control of high-prestige outlets. The whole social system of scientific publication, which had been a model of success for generations, performing a great variety of functions (diffusion, archive, quality-control, evaluation and allocation of resources), is suddenly required to rethink itself. And this crisis occurs in conjunction with the arrival of the new technologies of publicity, which threaten the monopoly of paper-publication with all its very useful structures and constraints. We should not underestimate the severity of this challenge to the social institution of science as we have known it.

In science, as in other areas of knowledge production, the new technologies dissolve previous boundaries. Previously the forms of publicity were atomised, in harmony with the production process and the conceptual objects. That is, 'the paper' was realised in a congealed text, printed in multiple identical copies on paper. It was the product of a defined original study by 'an author' (or, in industrialised conditions, a defined collection of authors). That study had its own distinct closed cycle from inception to completion, as reported in the paper. Even quality control was atomised, with anonymous reviewers reporting to a single editor, determining the fate of 'the paper'. The social conditions of industrialised knowledge production, particularly in relation to the reward system, which determined career opportunities, militated against leisurely investigations, as of the traditional natural history or even the reflective natural philosophy characteristic of 'gentleman-amateur' science. Accordingly, the atomised quick-returns project has come to dominate all aspects of the cycle. A parallel development in what can be called the practical ontology of science, fitted in with this style: the effort was to study simple, or simplified, systems, using conceptual objects and tools, usually statistical and mathematical, which enabled simple judgements to be made. Thus among biologists the emphasis became to focus on the smallest scales possible, from biochemistry down to genetics; whole, complex systems were deemed incapable of scientific study, as indeed they were under this definition of science. The process can be seen in its extreme parodic form in mainstream economics, where abstract mathematical models of the decisions of mythical atomic actors served to reinforce the politically driven assumptions of the discipline. In strong contrast, thanks to digital publication, the ongoing inquiry can now be a focus of a continuous flow of communal dialogue and development, in which there may be a temporary crystallisation of a 'product' as a matter of convenience. Leading journals in all fields now run blogs on their websites, providing alternate and informal channels of communication and dialogue. Thus, all the previous atomised social structures of quality, social control, publicity and access, and by extension the practical ontology of science, are thrown into confusion. Along with 'interdisciplinarity', complexity is now becoming a keyword in all sciences relevant to policy. We see here how all the different aspects of the production of scientific knowledge are mutually implicated in this transformation; starting with publicity, we have just shown how research practice and even practical ontology are affected.

Quality Control

The effects of the new technologies on the quality control cycle are, if anything, even more dramatic. Traditionally the quality assurance systems of science were run largely informally and largely confidentially. The mere fact of publication of a paper was taken to be its stamp of quality. All the processes of criticism and improvement were kept secret; the atomic unit of established knowledge embodied in the paper carried no penumbra of uncertainty or quality. Of course this system generally performed well, but it is highly sensitive to the quality of the quality-guardians and even more so of theirs. It is all too easy for peer review to degenerate into 'pal review'. For quite some time, the deficiencies of the peer-review system have been aired and considered, and the conclusion has always been that, rather like democracy, it is the worst possible system except for all the others. The technology of information contributed to this stasis: the sheer bulk of papers containing reviews, reports and revisions for a single publication would be inconvenient and expensive to make available for a wider scrutiny. Opening the files of documents on all publications would be impossible. But with the new technologies of information, we have new devices. Perhaps the most revolutionary of all the 'apps' recently invented is the Wiki. For, as Wikipedia itself has shown, with wiki all the editorial processes can be both convenient and transparent. On Wikipedia, every article appears with a sort of pedigree, and co-creators are invited in to contribute to the public quality assurance process. Of course the process can be, and often is, abused; but then the abuses are usually spotted quickly and a lively open debate ensues. In many ways, this approach is being incorporated into research science. What had hitherto been a remarkably closed institution, with little public scrutiny of its internal politics, and hardly any investigative journalism (with Mae-Wan Ho and Jonathan Latham providing the main exceptions), is now starting to be opened up. We can hope that the transition to effective 'openness and transparency' in the governance of science, starting with quality assurance, will be smooth; but it must come, and will come.

Consequences

Near the end of the cycle is Consequences. Traditionally it had been assumed that this had nothing to do with scientific discovery. The consequences of science were assumed to be essentially good and overwhelmingly benign in practice, and so the scientist could, with a good conscience, turn over his products to society for development and control. During the twentieth century, first in war and then in the fields of Safety, Health and Environment, consequences obtruded with increasing salience. A natural reaction was to bring all those issues under scientific control, with ‘risk’ becoming the dominant concept, displacing ‘safety’ and ‘danger’ in scientific discourse. This was defined as the product of the quantified probability of harm (always assuming that these had precise measures). There was even an ethical application: if a novel risk was no greater, quantitatively, than one already accepted, then only those who were misguided or malevolent would reject the new risk. Such analyses were applied in the early debates over civil nuclear power, and were discredited, along with the industry itself, by the disasters in the U.S.A. and U.S.S.R. By the end of the century, the inescapable presence of risk (still not ‘danger’) along with its characteristic politics, was analysed in the classic work *The Risk Society* (Beck, 1992). Now the issue of consequences is recognised as crucial in policy debates on new technologies, be they genetically manipulated crops or nanotechnology, as well as in broader policy debates, such as those on climate change resulting from industrialisation. However, the science that is universally accepted as necessary, finds it very hard to develop strength that is adequate to its tasks.

To understand this imbalance, we can see this new task as dealing with the Bads, rather than with the Goods that are the traditional goals of science. These problems will usually be ‘post-normal’ in having significant uncertainties and decision stakes. Even when there is little scientific uncertainty, vested interests can delay action by manipulating all relevant processes. The U.S. tobacco industry, ‘manufacturing doubt’, is the classic case; more are to be found in the seminal work *Late Lessons from Early Warnings* (European Environment Agency, 2002). Then, normally the bads are unintended consequences of mainstream science/technology done in the standard mainstream atomised way. For their study, the relevant fields will usually be marginal, and weak institutionally and politically, and perhaps even weak scientifically as well. Without any conscious intention, the rules of the mainstream scientific game are rigged against those who would pursue the science of bads. All this is changing rapidly under the new conditions of scientific practice. First, there is a structural asymmetry in the opposing sides of any debate on possible bads. The proposers are concentrated and organised, institutionally and personally. The opposition are typically a coalition of scattered aggrieved citizens joined up with underfunded NGOs. But just as the printing press and the rotary duplicating machine facilitated protest in earlier ages, the mobile phones and social media do so now. Also, since the protection of bads involves secrecy, the powers of new information technology to penetrate records and expose secrets redresses imbalances of knowledge and hence of power. Further, in modern society there are many protestors with education and applicable skills, so the traditional class divides are dissolved. The technique of 'Community Based Audit' where the data, methods and paradigms of proponents of developments are scientifically scrutinised by scientist-citizens and citizen-scientists working together as a preliminary to dialogue, is a valuable contribution to the science of bads. (Tattersall, 2011) We will know that science has genuinely entered its new epoch, when the science of bads becomes recognised as a subject worthy of being taught as part of a liberal education in science. A good start has been made in the announcement of the 'Oxford Principles' for responsibility in the governance of geoengineering research (Oxford Geoengineering Programme, 2012). They could provide the same service for the science of bads, that the 'Mertonian norms' for scientific integrity have done for traditional research.

A Problematic Case

A recent case encapsulates all these issues in consequences, or the science of bads, at the intersection of state regulation, populist politics and information technology. It started with a thoroughly traditional debate on bads, in this case the claimed possible harmful effects of a strain of GM maize, which is intended for use as animal feed in the EU. Although it had been cleared by the European Food Safety Agency (EFSA), powerful forces in France were opposed to it, and they derived support from a scientist at Caen named Séralini, whose tests, he claimed, showed danger (Butler, 2012). He had completed a new series of lengthy feeding tests, and had ambushed the opposition in its publication. The respectable scientific journal publishing the paper gave no advance notice to journalists, and the publication was accompanied by a film! In the row that followed, the critical statement by the EFSA was published on their website, and nothing could prevent the scientist from stating his rebuttal, at length, in the commentary section. Among the many criticisms of his work made by reputable scientists was one that alleged that he had not released his primary data. He promptly converted this into a challenge to the EFSA to release the data on whose basis they had decided that the product was safe. Why indeed were they so secretive? The EFSA soon called his bluff, launching an initiative for publication of data than had actually been planned for some time. (EFSA, 2013) As ever more authoritative criticisms piled in, something entirely different happened. This was a proposal by a group of anti-GM scientists in Russia, to perform a 'rat reality show' (Sharoykina, 2012), This would be a year-long Internet-TV

24/7 real-time feeding experiment to test whether GM products are harmful. Feeding procedures would be appropriately blinded, and there would be supervision by a committee including all tendencies in the debate. The sponsors claimed that in this way the public could have a trustworthy experiment to witness, and could then draw their own conclusions on the safety of GM. If the group cannot obtain resources for the show through orthodox channels, they plan to crowd-source the funding. There was no immediate response to this proposal. Is it a stunt? An opening to scientific demagoguery? Or a harbinger of a real 'science by the people'? Should we now start to speak of Zapatista science? For now, there is no way to know. But now that political power within science is diffused and perhaps also confused, the future is not foreclosed.

Citizen Science – An Emerging New Form of Science?

It is useful to draw together the threads of the previous discussions of citizens' activity in science, and to consider whether this is actually an embryonic new form of science. If so it would be a successor to the earlier phases, going back from industrialised/incorporated/academic to practitioner/gentleman-amateur. This new practice is based on a rapidly growing technology of social communication, has precedents in the "creative commons" culture in IT, and draws support from a great variety of institutions. Its own varieties of practice in relation to mainstream science have been described as: contribution, collaboration, and co-creation. The enormous differences in social organization between these roles are obvious. It can provide support for mainstream research, opportunities for individual creativity, and also means for opposition and protest. In this latter role, it can connect to the radical social-media movements, focused on issues of environmental and broader social justice. Is it developing a consciousness of itself and for itself, distinct from other forms of scientific practice? It is still too early to tell, and so far there is no sign of the internal conflicts that would inevitably accompany any attempt at self-definition. As it grows, it will need to establish procedures for quality-assurance, for excluding cranks and malefactors, and for relating to 'mainstream' science. Whatever happens, it is highly likely that in the next edition of this Encyclopedia, 'citizen science' will not be an afterthought.

Conclusion

We must keep a sense of perspective. All these developments in digital-age science, especially those on the populist fringe, are very much on the margin. The vast majority of scientific work is done just as it has been, in large labs with traditional structures of quality control. The immediate problems facing the scientific communities, such as deceleration of growth, shifting of activity to the East, disentangling the publications system, and shoring up the quality assurance system, continue to require attention from all concerned. Creativity flourishes, in a spate of new inventions as well as in debates on the scientific problems bordering philosophy and theology. But this essay is devoted to 'new forms of science', and so long as they are new they will by definition be on the margins, uncertain, indeed speculative in their future course. We might adopt the title of a recent prophetic book, *Science 3.0*, (Miedema, 2012) as the motto for our journey into this unknown and challenging future.

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