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Public perception of science and associated general issues for the scientist

D. Boulter

Department of Biological Sciences, University of Durham, South Road, Durham DH1 3LE, UK

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Abstract

This paper discusses how the public's criticisms that science is elitist, obscure, lacks control, tampers with the environment and is unethical arise in part from the nature of science itself or due to misunderstandings of what is science. An historical examination of scientific activity leads to the conclusion that whilst a strict definition of science is not possible, it can best be described as a powerful problem solving, self correcting activity with a specific critical attitude, criteria and coherent subject matter, differing only in scope and approach (pattern of cognitive fluidity, [Mithin, S., The Prehistory of the Mind. Thames and Hudson, London, 1996.]) to many other human activities. It is complementary rather than antagonistic to religious belief. Applications of science can change the environment for better or for worse and at this stage in man's evolution the environment merits special scientific attention. As biotechnology grows in importance, the nature of science itself and the means for its practical application will be called into question; 'pure' scientific culture may be about to be dramatically modified. Scientists will face the challenge of re-introducing science into mainstream culture by integrating wider cultural values into their scientific activities. © 1998 Published by Elsevier Science Ltd. All rights reserved.

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1. Introduction

Two previous papers (Boulter, 1995; Boulter, 1997) explored the public's perception of crop genetic engineering, discussed the scientists' responsibilities and the ways in which they might best respond with regard to the public's concerns. Public perception is fragmented but scientists have been charged by one constituency or another, with being isolated, arrogant, obscure, starting things which later get out of control, tampering with nature and of being unethical (blasphemous, uncaring and disrespectful). Some of these criticisms arise in part from the nature of scientific activities, others relate to misunderstandings of what science can and cannot do.

Scientists normally go about their business without much thought of the general nature of their activities. They can effectively act in this way because they go through an apprenticeship of learning 'on the job', the Ph.D. training in research, during which time they learn informally the mores and practicalities of scientific research. This training involves coverage of the existing information in the specialist field ('standing on the shoulders of giants' (Bragg, 1998)) and a critical understanding of the relationship between the individual's results and (a) those of others in the field and (b) in the wider scientific context. Training usually involves understanding experimentation, a major methodology (what is an experiment?, positive, negative controls, etc.) and in some fields the other major tool, mathematics. Furthermore, although often falling short due to human failings scientists are taught to be open (publish results in a form suitable for repetition), critical (attempt to falsify their theories) honest, generous to the work of others and unprejudiced (i.e. to use only strictly scientific criteria). By contrast most scientists receive little or no formal instruction about the history of their subject or of the place of science in

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society and culture. Whilst I am not advocating that these later topics should be a significant part of their training, scientists today do need to be aware of their changing status and of the need to respond to the public's demand for more openness (for example, see Rifkin (1998)). However, before attempting to communicate with non-scientists it is important for scientists to appreciate what constitutes the scientific enterprise and 'from where the scientist is coming', since the public's criticisms partly stem from the nature of science itself. Although not claiming to be exhaustive, this paper goes more deeply than the previous two (Boulter, 1995; Boulter, 1997) into those general issues of which the scientist should be aware.

2. What is science?

2.1. Towards a definition

2.1.1. Theory and experiment

In practice, scientific activity does not accord exactly with any proposed representational or philosophical model (Gell-Mann, 1994; Polkingthorne, 1996), i.e. it cannot be strictly defined or deliminited from all other activities.

If one looks at a mature science, such as physics, one finds that physicists are either classed as theoreticians or experimentalists. Theories are compressed packages of information, which set out a principle or set of principles (causal laws), applicable to many observations (observation statements). Theories contain explanations and are also used to make predictions which can be tested. To apply a theory or make predictions about an individual case, the theory must be supplemented with detailed information about that particular case, e.g. initial conditions. As there are often competing theories, the explanatory powers of a particular theory, or how well a theory predicts the results of test observations largely determines whether it is the accepted one, that is until such time as it may be displaced on the basis of the same criteria by a better one. Doubt and uncertainty is characteristic of science. Some theories unify and synthesise over a wide range of observations encompassing the regularities found in a number of phenomena previously thought separate (Gell-Mann, 1994).

Experimentalists, on the other hand, obtain data from experiments designed to test hypotheses (i.e. untested theories). Experiments set out to correlate the effect on an overall phenomenon, of a change in one factor which is varied, whilst the remaining factors thought to be involved are held constant. In practice, however, it is possible that factors may not in fact have been held constant during an experiment, or in some cases, other factors which are involved, although thought otherwise at the time, were not controlled. Different scientific disciplines vary in the precision with which experiments can be set up, e.g. the conditions of physical experiments can often be more precise than those of biological ones.

At the time of the scientific revolution in the 17th century, it was believed that science consisted of inductive causal laws obtained de novo by generalising data (observations) without the intervention of theory (Burns, Bloor, & Henry, 1996). At that time scientists stressed, that in contrast to prevailing scholasticism, the strength of science lay in its freedom from dogma, authority and preconceived values, hence their insistence on the shunning of theory. In this view, science stands or falls on the validity of inductive inference and inductivists emphasised the need for repeated observations under a variety of conditions (repeatability) and the fact that there were no contrary observations, if the generalisation (inference) was to be considered valid. Whilst the characteristic of repeatability applies

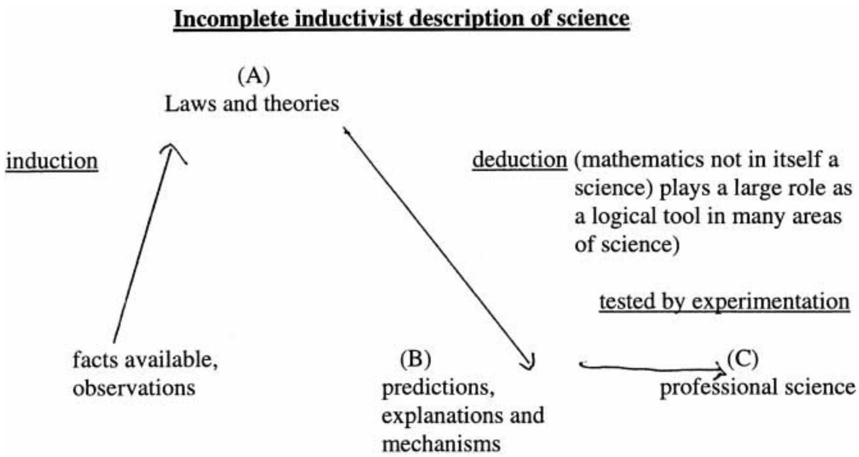

Fig. 1. Incomplete inductivist description of science.

to much of science, so much so that knowledge is only considered science when it is in the public domain (Ziman, 1968), the inductivists view that scientific theories arise solely from observations by induction whose validity is tested by deduced predictions (Fig. 1) cannot be justified on a variety of grounds (Chalmers, 1982). Induction is an incomplete description of scientific activities. For example, Einstein's special theory of relativity owed little to observations or experimental data but arose by Einstein imagining a ride on a wave of light; it derived from what he called 'thought experiments' (Bragg, 1998). Similarly, Galileo's deduction that all bodies fall equally fast was probably arrived at without dropping them from the Leaning Tower of Pisa but rather by logic from his answer to the question 'Does the presence of a light body help or hinder the fall of a heavy body?' (Bragg, 1998). Observations are 'theory laden' which determines what is observed and how the observations are interpreted. Observations are the judge but they are not theories. Scientific ideas and theories in fact may arise in many different ways, e.g. via inspiration, metaphor, dreaming or by isolating important from unimportant information and generalisations, i.e. personal creativity (Polanyi, 1958). This creative individuality gives rise to the perennial romantic question 'Would it have happened without that particular individual?'.

Historical evidence shows therefore that from the outset, experimentalists designed their experiments in response to theoretical ideas even if these were not those of establishment authority (Chalmers, 1982). As a description of science the connecting arrows of Fig. 1 must go back and forth and criss cross. Furthermore, scientists have often selected only those observations which fitted into a theory whilst discarding others which did not (Burns et al., 1996; Collins & Pinch, 1996). Theory and experiment are thus inextricably intertwined and not only theories but also observations can be discarded. In some instances, history has shown that the discarded observation was subsequently shown to be inaccurate and rightly discarded (incorrect observations, especially discarded ones, are not accommodated by strict inductivism). In other cases an observation was right but was wrongly discarded because it did not fit an existing theory, as additional factors, unknown at the time, had caused the misfit (Chalmers, 1982).

These considerations clearly rule out the suggestion that is sometimes made that science can be defined by its methodology (experimentation), i.e. that view emphasizes the predictive side of science at the expense of the explanatory side.

The condition that for an inductive generalisation to be considered valid, no observations contrary to the generalisations can exist, is untenable. The history of science shows that theories are not necessarily rejected when some data do not fit. In practice, the basic core of a scientific theory is protected by the use of 'saving' sub-hypotheses (Lakatos, 1974) although eventually, if sufficient contradictory data arise, the existing theory (paradigm) (Kuhn, 1970) is superceded by a new one. This, for example, has been the case in physics with quantum mechanics superseding Newton's laws, often, as in this case, the original theory being a limited case of the latter. In response to criticisms, falsifiability was proposed as the chief characteristic of science in order to overcome the philosophical limitation of inductive justification, i.e. scientific theories must be formulatable in a way which is potentially falsifiable. For example, classical psychology is not thought to be a scientific discipline by many scientists because its underlying principles are not formulated in a way that is potentially falsifiable. This is not to say that psychology does not have important things to say. Thus, Popper (1980) characterised science as a process whereby conjections, which were potentially falsifiable, led to predictions which could be experimentally tested. Acceptance or otherwise of the conjecture (hypothesis) would depend on how well the hypothesis fitted the obtained test data. According to Popper (1980) predicted correlations of a theory don't provide proof or certain explanation, the closest to which we can come is a succession of unsuccessful attempts at falsification.

Falsification has played an important role in 21st Century science in the way hypotheses are set up (or judged suitable) for testing (Medawar, 1969). Nonetheless, falsifiability is not a complete description of science; not all statements in science are strictly falsifiable (Chalmers, 1982). Darwinian evolution is a case in point. This is a theory initially based on interpretation of data without experimental support and not strictly falsifiable. Its continued acceptance is based on it fitting with many other scientific results, some of which are experimental and others providing plausible mechanisms for it. This illustrates an important characteristic of science that theories to be accepted must have coherence with the rest of scientific data (at best be unifying and progressive) leading to further questions and not to dead ends. This means, however, that new questions to be addressed normally evolve from the existing body of science (Ruse, 1996), so limiting the type of questions that are asked. It has already been noted that potential falsifiability can limit the questions addressed by scientists as does the requirement that observation is the judge (excludes 'should' and 'what value' questions).

In science, different procedures have been used at different times and science is an historical complex body of knowledge; it consists of a large body of data/observational statements underpinned by scientific theories and 'causal' laws which form a structured, coherent whole.

In the final analysis, knowledge is incorporated into the body of science by the choices of professional scientists and there is a complex infrastructure of meetings, peer review funding, journals and professional bodies to underpin the decision process.

2.1.2. Probability, hierarchy and mechanism

Science in its search for causes, formulates laws which are statements of probability (things are likely to be so). Laws are in turn explained by more general laws, e.g. the laws of quantum electrodynamics can in principle explain a large amount of chemistry (but only when the special conditions for chemistry are fed into the equations also). Science then is characterised by hierarchies and the idea of reductionism is born (laws can be replaced by more general laws, reducing finally to the fundamental laws of modern physics). Strict reductionists have over-emphasised this characteristic of science denigrating those parts of science (e.g. ecology) not engaged in the bottom-up search for fundamental mechanisms (Gell-Mann, 1994). However a more correct and balanced position to that of reductionism would, for example, see a biologist investigating an ecosystem at the level of whole organisms as not invoking additional forces to those of the fundamental laws (i.e. reductionist) but also as investigating biological regularities at the level of whole organisms, emergent properties (top-down) which have arisen from chance events as well as from the fundamental laws and who would have no success working from the bottom-up. A similar criticism can be made of reductive 'theories of everything' based solely on particles and forces.

As science searches for deeper underlying causal laws it also becomes involved with processes and mechanisms which are not directly observable (Scruton, 1966). Again some strict reductionists wish to exclude non-mechanistic phenomenon from science. That said, explanations at the mechanism level have the practical advantage of being used to give a better chance of effective interaction.

2.1.3. Resumé

Science then consists of a large body of data/observational statements underpinned by scientific theories and 'causal' laws which form a structured whole, the boundaries of which are vague and difficult to define. Nevertheless, professional scientists do draw boundaries to their specialist fields of science excluding what they reject as non-science. Accepted data must be repeatable (science only becomes science when data are in the public domain (Ziman, 1968)) and theories must have coherence with the rest of scientific data (at best be unifying and progressive) leading to further questions and not to dead ends. This means, however, that new questions to be addressed normally evolve from the existing body of science (Ruse, 1996), so limiting the type of questions that can be asked. Sometimes attempts have been made to answer questions, which are not within its remit, for example, is there a God?, leading to 'bad science'.

Clearly, it is not as some have suggested (Feyerabend, 1975) that anything can go in science which probably has a particular cognitive fluidity (Mithin, 1996). However, science cannot be logically justified as being the truth and its operations and methods cannot be absolutely distinguished from those of the humanities only by their scope. So it is unjustified to suggest science is the only main way to the 'truth' of the world. Many of the questions of great importance about human relationships and purpose (the provinces of the arts and religion) are outside its present scope and many, but not all, feel in the future also. Lastly, unlike philosophy, science is a cognitive knowledge acquiring activity (Hacker, 1997).

Science then is the best way to solve some problems (find things out). It boosts morale in that it gives us confidence that we are not completely at the mercy of the environment and can reasonably solve most problems (mathematic probability predictions for example led to quantitised risk taking and the modern world of the global market) Science is badly needed in the future to give increasing management of the environment for food production, disease control, biological innovations, increased leisure time and material comfort.

3. Science, the scientist and the public

This section discusses those public concerns about science which arise out of the kind of activity science is or is believed to be.

3.1. Isolation, infallibility, arrogance, obscurity, lack of control

The preceding analysis of science shows that science isn't so different from other practical human activities. Scientists are not the only ones to see regularities in nature and use them to guide future actions; pattern recognition is a natural habit of the mind. This similarity of science to non-science and everyday affairs hasn't been emphasised enough by scientists who have rather seen themselves as a thing apart (this isolationist attitude was an initial criticism of science by Hobbes in the 17th century (Shapin & Schaffer, 1985)).

As pointed out by Gell-Mann (1994), non-scientific pattern-recognition schemes have been widespread during human history and are still common, e.g. sympathetic magic (similar things *must* be connected, e.g. rain ceremony involving water and the inducement of rain), but these beliefs do not have the objective success as does much of science with its more strict criteria. The difference between myth, pragmatism and science can be nearly encapsulated in the history of the search to find a solution to the fungal disease of wheat caused by the rust fungus (Large, 1946). This fungal disease of wheat which causes a reddish brown coloration of wheat used to appear regularly in Roman times at about the same time as the appearance of the Dog star in the Mediterranean night sky. This regularity led the Romans to believe in the myth that the disease was caused by the star's malign influence and magical rights were enacted to prevent it (presumably with little success). Much later, but before the cause of the disease was proven scientifically, some countries, but not England, passed laws for the eradication of barberry bushes when growing in the vicinity of wheat fields. This was based on the observed correlations between the occurrence of the disease and locally growing barberry, so arriving at a practical solution the reasons for which only became apparent later. Eventually in the mid-19th century De Bary, a mycologist, elucidated the life cycle of the rust fungus *Puccinia graminis* and isolated the various stages of its complex fungal life cycle, from diseased wheat plants and the secondary host barberry. He showed that inoculating wheat in the right environmental conditions with rust spores inevitably led to the appearance of the disease and he further showed that associated secondary fungal infections were not the cause, proving by scientific experiments the true nature of the disease.

However, when assessing the importance of myths it must be remembered that enduring myths normally serve other functions from those of science. Enduring myths are neither true or false, but provide a framework within which to see ourselves (Monk, 1998).

If science cannot be defined strictly and if not all science findings and theories have experimental backup, what is it different about science? Formally perhaps, nothing, but in practice the following: (1) an attitude to try and disprove ones hypotheses and theories by the most powerful tests available, e.g. critical experiments and (2) the requirement to fit new findings into a structured scientific corpus of knowledge in order to be accepted and the corollary of the restriction of the questions that can be asked. By way of illustration of the latter, the following is an example given by Deutsch (1998). The hypothesis that 'eating a kilogram of grass cures a cold' is falsifiable since it leads to testable predictions but would probably not be tested, even so, as the experimental results would be deemed unlikely to be explanatory, as there are no existing suitable mechanisms within the present scientific body of knowledge. I add, however, we do know that plants contain anti-viral compounds and so, as more information accrues, the hypothesis might one day be considered suitable by scientists for testing. In this day and age the public are often less reticent about the questions they ask of nature, leading perhaps unfairly to the journalists' criticism that scientists seem further removed than ever from what the public find interesting.

The public has, until recently, viewed science as infallible, hence the strong reaction when some of its applications have been shown not to be beneficial. Some scientists have been partly responsible for conveying this omnipotent view of science by stressing mechanical models of the universe, reductionism and more recently the search for 'reductive theories of everything'. In contrast, the description of science given in this paper shows that science is not infallible but changes, evolves and can only approximate to the 'truth', doubt and uncertainty is part of a scientific attitude. To agree with this description is to admit that in the past scientists have made mistakes and they should acknowledge the fact where appropriate when communicating with the public. That said, scientists do believe that science evolves to increase the sum total of practically reliable knowledge. This is why Kuhn's (Kuhn, 1970) description of science is limited and doesn't explain the succession of theories leading to deeper insights except in terms of his overemphasis on sociological and psychological aspects of science which is clearly inadequate. The argument that the application of science (technology) rather than science itself is what is being called into question, is now no longer a socially acceptable point of view.

Scientists are often perplexed as to why they should be deemed arrogant by the public, especially as scientific activities are modified to some extent by social considerations. However, science is a structured whole, the boundaries of which are drawn by the scientists themselves via a complex infrastructure. It is important, therefore, for scientists to appreciate how professionally elitist this may appear to the public and that if they unconsciously aggravate the situation they will be deemed arrogant. Self-regulating professions are now expected to be more open and change of funding mechanisms for science will aggravate this trend.

The fact that the public finds much of the detail of science unintelligible is again inherent in science itself. Science often investigates mechanisms which are not directly observable and which are counter-intuitive (e.g. quantum mechanics). Also, in addition to jargon, much of the language of science is mathematical and difficult to comprehend.

Another public concern (Boulter, 1995) is that scientists start things without always realising their consequences (i.e. they lose control). The public's concern is usually with regard to specific technological developments (e.g. nuclear energy) but the history of science shows that a characteristic of science generally is that it is very difficult to predict where discoveries will eventually lead. The new is needed but is always to some extent unpredictable in its consequences. Curiosity is a main motivating force for most scientists and possible practical applications (although often used to justify funding) are often far from their thoughts. This is why the requirement to satisfy the criterion of need (the 4th hurdle) before a piece of scientific investigation proceeds, which has been often suggested, is contrary to the true spirit of scientific endeavour, (but see later). New science initially arises from the cutting edge of the activities of professional scientists and is at that stage unregulated (sometimes scientists regulate it themselves, e.g., the initial self-imposed moratorium on gene cloning (Boulter, 1995). Facing up to this dilemma is becoming increasingly important.

3.2. Unethical

3.2.1. Science and religion

It is sometimes claimed (Appleyard, 1992), that science erodes belief in a transcendential God, but I do not think it is generally the case for the following reasons:

Science searches for causal laws which are themselves explained through more general laws but in doing so leave some questions unanswered, e.g. why these particular causes exist. Furthermore, science concerns itself with events and not with those types of causes (reasons) which are endowed with a moral sense, i.e. those not concerned with whether explanations are true or false but whether good or bad, e.g. scientists show that arsenic was the cause of death not why it was administered in the first place (Scruton, 1966). Questions in those areas, i.e. ethics, purpose of life and belief in God lie in the orbit of religion and the arts, not science and answers are not based on tangible events but revelation, mystical experience and intuitive belief. Logically, these beliefs cannot, therefore, be eroded by the explanations of science even though a scientific attitude may spread doubt. If for the individual that occurs or if a scientific explanation suffices, since some scientists believe science uncovers reality (Deutsch, 1998) that is a result of an individual's psychology and training and not to be laid at the door of scientific explanation. As we grow up we sublimate basic biological drives, e.g. reproduction and self-preservation, into a range of social activities, aims and relationships whose present explanations lie outside the scope of science. In the future, our knowledge of genetics, neuro-science, psycho-evolution and cognitive archaeology may be able to provide precise explanations of human nature and behaviour. Just as the underlying mechanisms of the physical laws of nature describe processes which we can not observe directly, e.g. those of quantum mechanics, so the underlying mechanisms of human behaviour may be very different from those observed at the surface level of our interpersonal relationships as portrayed and debated in literature and the visual arts.

Nevertheless, whatever the logical position, many will see claims by scientists of the possibility of Theories of Everything (Deutsch, 1998), as scientists playing God, or as Hawking puts it (Hawking, 1988) we should know the mind of God. Even the claim (justification, apologia) that science will feed the growing world population will be seen by some as playing God. Fortunately, most scientists are encouraged by their training to be humble before nature.

3.2.2. Tampering with nature

The evidence that science interferes with (alters, controls) nature has led to charges of scientists being disrespectful and lacking in care. The fact that man by his efforts has become so dominant both spatially and numerically relative to other animals means his effect on the environment must be given special scientific attention. Applications of science can change the environment both for better and for worse and consideration of the environment is a good example of a larger dimension in which science and the spirit can meet (Carson, 1965).

4. How to integrate general public with the development of science policy

The difficulty of understanding science coupled with the sheer numbers concerned ensure that involving the public in science policy making is a recalcitrant problem. Thus the consensus conference approach (UK, 1994) involving as it does small numbers of the public is on too small a scale to be useful whatever its effectiveness might be. Evolution has ensured that man's perception of the natural world makes much scientific explanation of it counter-intuitive, plus the additional difficulty that cultural factors often perturb the public's appreciation of scientific methods.

Do we even know what it is the public want to know about science? Finding that out might at least be a start.

Whereas the problem with respect to the public is mainly one of logistics, education and engendering dialogue not confrontation, the problem for the scientific community is more conceptual, involving a kind of juggling act. Science is a social activity in that its direction and progress are influenced by the fact that society funds it. Science is also a social activity in that science is regulated by the mores of the scientific community as set out above by the selection of data, acceptance of new theories, choice of problems to be tackled. Nevertheless, strict scientific criteria strive to exclude cultural values such as progress and need, e.g. see Ruse (1996) for an example of how the idea of progress has distorted the scientific Darwinian evolution debate.

Perhaps as Lévy-Leblond has suggested (Lévy-Leblond, 1998), scientific culture, as described in the paper, is coming to an end. Scientists and the public are one and the same, the former like many other sectors, having specialist knowledge. Scientists must accept the challenge to re-introduce science back into mainstream culture and learn to integrate such wider cultural values into their scientific activities.

5. Conclusion

As we enter the next millennium, the introduction of biotechnology into the market place, will gather pace and will pose questions for scientists, industry, regulators and the public alike about the nature of science and the means for its practical application.

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