

p.21

The 'technocratic' view of science is that of a basic factor of production, needing ever-increasing supplies of highly-trained 'scientific manpower'. [...] It assumes 'science' to be an independent, self-contained factor in the situation, needing only financial support and administrative planning to provide unlimited blessings for us all.

p. 22

[...] the assimilation of the production of scientific results to the production of material goods can be dangerous, and indeed destructive of science itself.

p.22-23

Two separate factors are necessary for the achievement of worthwhile scientific results: a community of scholars with a shared knowledge of the standards of quality appropriate for their work and a shared commitment to enforce those standards by the informal sanctions the community possesses; and individuals whose personal integrity sets standards at least as high as those required by their community. If either of these conditions is lacking-if there is a field which is either too disorganized or too demoralized to enforce the appropriate standards, or a group of scientists nominally within the field who are content to publish substandard work in substandard journals-then bad work will be produced. This is but one of the ways in which 'morale' is an important component of scientific activity; and any view of science which fails to recognize the special conditions necessary for the maintenance of morale in science is bound to make disastrous blunders in the planning of science.

p.28

If the study of science is abandoned by all except those who are content to be manpower-units, then within a generation there will be no one competent and concerned to analyse and expose the ecological blunders produced by our bureaucratic technology. In that case, the hippies will have been proved correct, and we can anticipate at least some centuries of barbarism before the next try at civilization.

p. 39

[Quote from Helmholtz]

Who, when Galvani touched the muscles of a frog with different metals, and noticed their contraction, could have dreamt that eighty years afterwards, in virtue of the self-same process, whose earliest manifestations attracted his attention in his anatomical researches, all Europe would be traversed with wires, flashing intelligence from Madrid to St. Petersburg with the speed of lightening? In the hands of Galvani, and at first even in Volta's, electrical currents were phenomena capable of exerting only the feeblest forces, and could not be detected except by the most delicate apparatus. Had they been neglected, on the ground that the investigation of them promised no immediate practical result, we should now be ignorant of the most important and most interesting of the links between the various forces of nature....

Whoever, in the pursuit of science, seeks after immediate practical utility, may generally rest assured that he will seek in vain. [...]

In conclusion, I would say, let each of us think of himself, not as a man seeking to gratify his own thirst for knowledge, or to promote his own private advantage, or to shine by his own abilities, but rather as a fellow labourer in one great common work bearing upon the highest interests of humanity.

H. von Helmholtz, 'On the Relation of Natural Science to Science in General', in *Popular Lectures on Scientific Subject*, 1st series (London and New York, 1893), pp. 24-28.

p. 53

[when discussing runaway technology]

Those who take the decisions to plunge into ever greater 'progress' in this work are not afflicted by any special wickedness or even irresponsibility. They are merely continuing the attitudes and practices inherited from the industry of the past, which might be called 'myopic engineering'. Provided that a particular development was technically viable and not at risk of penalties under the law, then so long as it seemed likely to make a profit, it would be adopted with no further thought of its consequences.

p. 57

[when discussing 'Social Problems of Industrialized Science'] four abuses, shoddy science, entrepreneurial science, reckless science, and dirty science [...]

p. 58

The need for good morale is never mentioned in general discussions of science directed to a lay audience; and this is evidence that hitherto its presence could be taken for granted. For doing good scientific work is strenuous and demanding, and the quality of the work done in any field of science is dependent, to a great extent, on the integrity and commitment of the community of scientists involved.

p. 71-72

1. Scientific inquiry is a craft.
2. The objects of this work are not natural things, but are intellectual constructs, studied through the investigation of problems.
3. The work is guided and controlled by methods which are mainly informal and tacit, rather than public and explicit.
4. The special character of achieved scientific knowledge is explained by the complex social processes of selection and transformation of the results of research.

p. 81

no set of data can be 'perfect' as a report of properties of the objects of investigation, nor can it be independent of the plans and expectations for the later stages of the work.

p. 86 note

The hazards of the transition from data to information in descriptive sciences is shown particularly well by what might be called the Case of the Bulgarian Pigs, described in O. Morgenstern, *On the accuracy of economic information*, 1st ed. (Oxford University Press and Princeton University Press, 1950), p. 19. The data are the number of pigs in Bulgaria on 1 January 1910 and 1920; these were 527,311 and 1,089,699 respectively. The information derived from this pair of figures was that the number had more than doubled during the decade. Unfortunately, the inference was fallacious; what had happened in the interim was that the calendar had been changed from the Julian to the Gregorian, so that the peasants celebrated Christmas in January (new style) just as the Soviet Union celebrates the 'October Revolution' in November. Just half the pig population is slaughtered immediately before Christmas; and so the extra pigs on 1 January 1920 were merely awaiting their Yuletide extinction.

p. 110

Until very recently at least, the implicit assumption in the writings of the history of science (especially at the level of schoolbooks and popularizations) was that our sort of science is the obvious and natural way to study the world of nature, merely the application of unfettered common sense. Periods and cultures which failed to produce effective natural science of our sort were condemned for an almost wilful neglect. By the same assumption, great discoveries in science have been presented as the

perception of the obvious, and the failure of a great discoverer to get the thing quite right is the occasion for an apology on his behalf. In this way, the history of scientific achievements comes out as a succession of one-eyed men in the kingdom of the blind. The question of why it required a great man to get even one eye open, and still the question of why he happened to come along at just that time, are rendered incapable of being asked, let alone answered.

p. 115

Any serious study of the history of science destroys the assumption of the simplicity of a scientific discovery.

p.146-147 [on Methods]

The body of methods associated with any field is partly informal and even tacit; it is not transmitted by the same public channel of communication as scientific results, but through an informal, interpersonal channel. Hence the testing, criticism, and improvement of the methods for a field must proceed by means quite different from those applicable to its scientific results; and in this aspect of scientific inquiry, the character of the community engaged in the work is thus crucial for the nature and quality of its achievements.

p. 153 [When discussing Judgements of Adequacy]

For statisticians do not simply say that a correlation is 'significant' or 'not significant'; rather, they will speak of significance at a certain level. Those who have any craft skill in the use of such tools will appreciate that the significance level to be adopted is not assigned by God, but must be decided by the user. The decision will be based on estimates of the direct costs and the risks associated with each level. For each level of significance involves the possibility of two sorts of error: of rejecting worthwhile information, or of allowing dubious information to pass. The more stringent the test chosen, the safer; but also the more costly, because of the extra time, care, and resources required for producing material that will pass it. The choice of a particular level of significance must depend on a judgement of what degree of safety is required, for that component in its context in the total problem. And this judgement must be based on general criteria of adequacy applied to that particular situation. There can be no perfectly safe test of the quality of the material, and neither can there be a certainly correct decision on the degree of stringency of the test.

p. 158

the great mathematician Gauss observed that 'lack of mathematical culture is revealed nowhere so conspicuously, as in meaningless precision in numerical computations'. Quoted from O. Morgenstern, *On the Accuracy of Economic Observations*, p. 99.

p. 176

If there were not a test of each paper before its acceptance by a journal, then every intending user would be forced to examine it at length before investing any of his resources in work which relied on it. Under such circumstances, the co-operative work of science as we know it could not take place.

p. 179

For it is possible for a field to be diseased; for the ruling methods to be such that ineffective or shoddy work is accepted or even enforced. But the establishment of the existence of such a condition, and even more the attempts to reform it, are problems of a different sort from those which the field is devoted to investigating. Moreover, while gross errors in technique can be detected by the discovery of pitfalls in published work, the more subtle components of method are not easily accessible to anyone who has not already invested a part of his life in working in the field. Thus, reforming a diseased field, or arresting the incipient decline of a healthy one, is a task of great delicacy. It requires a sense of integrity, and a commitment to good work, among a significant section of the members of the field; and committed leaders with scientific ability and political skill. No quantity of published research reports, nor even an apparatus of institutional structures, can do anything to maintain or restore the health of a field in the absence of this essential ethical element operating through the interpersonal channel of communication.

p. 185

science does not begin with facts; indeed, when facts are achieved (and recognized as such by the community) the process of achievement of knowledge in that particular area of research has passed its most challenging phase and is settling down to a routine.

P. 187

an hypothesis is something which we may fully expect to be falsified, and a model is claimed only to have some analogical relation to reality.

P. 191

facts do not come at the beginning of a project of scientific inquiry, but are the outcome of a lengthy process of work, with the individual phase of the investigation of a problem followed by the social phase of the testing, through use, of its solution. [In a footnote the Ravetz explains 'I am of course developing insights first argued by Karl Popper' but then the Ravetz goes on to say that this needs a 'self-critical attitude [...which] will not be sustained in the absence of a genuinely ethical commitment shared by the members of a scientific community'.

p. 287-288 [Section 'Industrialization of Science and Quality Control']

with the industrialization of science, certain changes have occurred which weaken the operation of the traditional mechanism of quality control and direction at the highest level. The concentration of the scientist's audience towards those who advise the agencies has not merely caused in him a tendency to neglect the diffuse consensus of expert colleagues; it has also made him less dependent on the judgement of his lay colleagues in the university system.[...] Under these conditions, the system of assignment of prestige, always a delicate and unstable thing at the best of times, cannot operate to any worthwhile effect. [...] The extent to which such developments have already damaged the mechanisms of quality control in science is impossible to estimate. [...] there are no direct means whereby anyone outside the world of science can exercise quality control on science. The products of the craft work of scientists are intelligible, and valuable, only to other scientists. [...] The problem of quality control in science is thus at the centre of the social problems of the industrialized science of the present period. If it fails to resolve this problem, and does not develop new techniques for restricting prestige and rewards to those who deserve them, then the immediate consequences for morale and recruitment will be serious; and those for the survival of science itself, grave.

p. 295-296 [Section '*Quality Control of Skilled Tasks: the Insufficiency of Self-Interest*']

'Wherever there's a system, there's a racket to beat it.' [Footnote: 'For this aphorism I am indebted to an anonymous US tram-driver in Atlantic City, New Jersey, in 1952']

[...]Arguments [...] showing how a common good can derive from an aggregate of selfish decisions, are as old as the science of political economy. They all share the same logical fallacy, and all neglect the incommensurability of social cost and private benefit which can frequently occur in human actions.[Macur Olson's Logic of Collective Action is acknowledged in footnote]

p. 312-313 [After discussing ethics in science after Karl Popper, Michael Polanyi, Robert K. Merton]

All three identified dangers to science: for Polanyi they lay in bureaucratic direction and control; for Popper they lay in the dishonesty latent in the denial of criticism; and for Merton they lay in the inherent conflict between the norms of co-operative scientific endeavour and those of lay society and the State.[...] The idealistic approach involved the assumption of the excellence of scientific inquiry as a permanent reality, and from this derived an enlightened ethical commitment of scientists as a logical consequence. My argument has used the same components, but has changed the mode of causality. I make the more realistic assumption that the health and vitality of scientific inquiry are not guaranteed, either by the objects of inquiry or by the social aspects of the work. Hence, unless there is an effective ethic, even more refined than a 'professional ethic', this very delicate and sensitive work will not long continue to be well governed or well performed. Yet it is unlikely that the ideological basis for such a scientific ethic can continue to be found in religion and philosophy, nor its practical roots in the refinement of the code of conduct of an elite class. Therefore the ethical basis of future

excellence in science must lie in some other ideals and experience; perhaps in a humanitarian commitment, necessarily interpreted in a much more sophisticated fashion than ever before.

p. 318-319 [on scientific problems, technical problems and practical problems; Aristotle's Nicomachean Ethics is acknowledged in footnote]

we describe as 'technical' problems those where the function to be performed specifies the problem itself. The goal of the task is fulfilled, and the problem 'solved', if and only if that function can be adequately performed. A design team that produces a device that performs a function different from the one assigned, will not usually be congratulated on its initiative and independence.

[...]

there is a class of 'practical' problems in which the goal of the task, in principle, is the serving or achievement of some human purpose. The problem is brought into being by the recognition of a problem-situation, that some aspect of human welfare should be improved. Such problems involve intellectually constructed objects rather than ordinary 'common-sense', as we see from programmes and debates on such issues as 'education', 'poverty' and 'health'.

p. 344

any bureaucracy has built-in barriers to the recognition of failure in the performance of its functions.

p.346

[a naïve belief is] that 'scientific method' can be applied in a simple and straightforward fashion to [practical] problems. [Ravetz gives the example in footnote:] Karl Pearson, in *The Grammar of Science*, strongly advocates the application of the methods and the results of science to social problems. His chosen example was the problem of the poor; and he used Waissman's theory of the germ-plasm (with reservations in his account of the theory but not in his practical conclusions) to condemn that ill-conceived philanthropy which encourages such 'inferior stocks' either to increase their numbers or to mix with those superior to them.

p.349

'Never believe anything until it's been officially denied.' It is perhaps less serious that the general public is ignorant of these limitations on the reliability of expert pronouncements, than that their superiors in positions of decision-making must, by bureaucratic etiquette, place some reliance on their conclusions and recommendations. [There is a footnote here with a quote of President Pompidou about technicians being the safest route to ruin (the quickest the gambling and the pleasantest is women)]

p. 360 [A Mumfordian bit – Lewis Mumford used for the example]

In any debate over a proposed innovation, the most loud and consistent voice will be that of the group promoting the new device. At best, they will be honest practitioners of traditional myopic engineering; their problems are defined in hard, quantitative terms, and their projected solution may well be the only one possible on the assumption that the technical and social context of the problem remains unchanged. But the engineers have recently been joined by the apostles of runaway technology, who when all other arguments fail have the last refuge of 'progress'. In practice this means that if an existing device can be 'improved', usually by being made larger, faster and more expensive, then it is violating a law of nature to abstain from doing so. [...] the history of technology is quite Hegelian, seeing the efforts of the past as the unfolding of the Idea of the Perfect Device of the present or of the near future.

p. 362

The problem of achieving effective democratic control on the decisions of technological innovation is beset by the many difficulties we have seen: the combination of contrary purposes, with bureaucratic operation, and the different ideologies of the various groups involved. Yet if this problem is not solved, our social lives will inevitably come to be ruled to an increasing extent, by blundering

bureaucrats and experts. Worse yet, this will be recognized as a new form of oppression, [...] [there is here a quote from Hannah Arendt (On Violence) on the 'rule by Nobody']

p. 366 [Chapter on IMMATURE AND INEFFECTIVE FIELDS OF INQUIRY]

the difficulties of working in an immature or ineffective field are serious and manifold. Added to the basic difficulties of having to do research in a field where the pitfalls are still unidentified, there are the social constraints forced by the pretence of maturity. The situation becomes worse when an immature or ineffective field is enlisted in the work of resolution of some practical problem. In such an uncontrolled and perhaps uncontrollable context, where facts are few and political passions many, the relevant immature field functions to a great extent as a 'folk-science'. This is a body of accepted knowledge whose function is not to provide the basis for further advance, but to offer comfort and reassurance to some body of believers.

Page 368 footnote

This instability in the ineffective sciences was of crucial importance in the development of the ideas of Thomas Kuhn. In the Structure of Scientific Revolutions, he reports on his experience at the Center for Advanced Studies in the Behavioural Sciences, '... I was struck by the number and extent of the overt disagreements between social scientists about the nature of legitimate scientific problems and methods. Both history and acquaintance made me doubt that practitioners of the natural sciences possess firmer or more permanent answers to such questions than their colleagues in social science. Yet, somehow, the practice of astronomy, physics, chemistry or biology, normally fails to evoke the controversies over fundamentals that often seem endemic among, say, psychologists or sociologists' (p. x).

p. 383 [Section Technical and Practical Problems and their Hazards]

It is when immature sciences are enlisted for the solution of practical or technical problems that the most severe strains arise. For this engagement inevitably leads to deceptions, of self and others, compared to which those on the academic scene are but minor slips. A discipline which is unable to establish facts even within its closed world of controlled experience is much less capable of genuinely drawing conclusions about the problems of a raw and unstable reality.

p. 386-387 [Section Folk-Science]

[folk-science] is a part of a general world-view, [meant to] provide comfort and reassurance in the face of the crucial uncertainties of the world of experience. [...] it can be argued that the 'new philosophy' of the seventeenth century, with its disenchanting and dehumanized world of nature and its appreciation of closely controlled experience, itself functioned as a folk-science for its audience at the time. For, as it appeared then, it promised a solution to all problems, metaphysical and theological as well as natural; and it gained a stable social base long before its achievements were commensurate with any of its claims. Indeed, we may say that the basic folk-science of the educated sections of the advanced societies is 'Science' itself in various senses derived from the seventeenth-century revolution in philosophy.

p. 389

particular results of a matured field may (with suitable interpretation and vulgarization) suddenly become a component of a leading folk-science, and embark on a new career independently of the thoughts and desires of their creator; such was the case with 'Darwinism'.

p. 391

For some generations up to the present time, most academic natural science has been 'ideologically neutral'; and indeed this neutrality has been invoked by propagandists for science, as a reason for its complete autonomy of goals from outside interference. The exceptions to this neutrality have been little studied; one which may be historically significant is the close association, in the early twentieth century, of the science of genetics with a generally reactionary and elitist folk-science of 'eugenics'

p. 396

Economics is doubtless the folk-science of all those committed to an economy planned to any degree; in spite of the vacuity, or irrelevance of most of its theory, and the patent unreliability of its statistical information, it ranks as the queen of the sciences in the formation of national policy.³⁸ Debates over economics as a discipline are almost all debates over political economy; and while the critics, of the far Right and libertarian Left, ruthlessly expose its fallacies and inadequacies, academic students are carefully ushered through the accepted doctrines in blissful ignorance of these difficulties.

p. 398

Indeed, it frequently occurs that a problem-situation is recognized and analysed by isolated scholars for years before it suddenly comes to exist as a political event. The eventual popular recognition may be a result of serious disturbances of the accepted order of things (such as mass action in the form of riots, an economic crisis, or a war); or a particularly eloquent account of the problem may reach the public just as its previous cares are losing their dominance on its perceptions. However, even for that new perception to take place, it must be coherent with the informal categories of the ideology of that public; and it is perceived in the terms of its accompanying explanation, cast in the relevant folk-science. The function of such explanations is to minimize the threat displayed by the problem-situation; this is done either by explaining it away altogether, or, if this is impossible, to give assurance of the possibility of its comfortable resolution. If these tasks cannot be accomplished, then the ideology of that public faces collapse, and the people themselves are threatened with the disintegration of their world.

p. 405 [CONCLUSION: THE FUTURE OF SCIENCE]

For several centuries, the understanding of science has been conditioned by a belief in the separateness of knowledge and society.[...] That simple faith is no longer adequate for its function of maintaining the integrity and vitality of science.[...] The argument of this book has attempted to exhibit the ways in which genuine scientific knowledge can be a product of a social endeavour, and yet embody truth, at least within the fundamental metaphysical framework of the civilization in which it is achieved.

p. 407

No formal system of imposed penalties and rewards will guarantee the maintenance of quality, for the tasks of scientific inquiry are generally too subtle to be so crudely assessed; nor will the advantages to an individual of a good reputation of his group be sufficient to induce a self-interested individual to make sacrifices to maintain it. Only the identification with his colleagues, and the pride in his work, both requiring good morale, will ensure good work.

p. 408

the conditions of industrialized science present [leading scientists] with problems and temptations for which their inherited 'scientific ethic' is totally inadequate.

Ibidem

Conflicting ideologies and purposes are at the heart of every urgent practical problem; they lack the accepted criteria of quality for their solution; the sciences involved in them are usually immature; and in their execution they are prone to distortion by the natural tendencies of bureaucratic operation. Because of the increasing recognition of new practical problems, immature sciences are assigned tasks which they are not strong enough to accomplish properly; to their internal difficulties (aggravated by the necessary pretence of maturity) are then added those of hypertrophy. When involved in the solution of practical problems, they also function as folk-sciences; and the resulting confusion of the different sorts of problems and their appropriate styles of work can result in total demoralization and corruption.

p. 418

We can say that an activity is corrupt when the actual goals of the tasks accomplished are contrary to the professed social functions to a degree that a public trust is betrayed.

p. 420

There is naturally a great temptation for the leaders of science to attempt to gain the best of both worlds for as long as possible: to extol the virtues of the free search for truth to one audience, and to promise useful services to another.

p. 429 [On a critical science]

a completely solved problem in critical science is more demanding than in either pure science or technology. In the former, it is usually sufficient to obtain a conclusion about those properties of the artificial objects of inquiry which can be derived from data obtained in the controlled conditions of experiment; in the latter it is sufficient for an artificial device to perform its functions without undue disturbance by its natural environment; while here the complex webs of causation between and within the artificial and natural systems must be understood sufficiently so that their harmony can be maintained.

p. 434

The dreams of the romantic, philanthropic, radical philosopher prophets cannot move towards realization by the accumulation of facts or of battalions. Rather, they exist through a discontinuous, perhaps erratic, series of crises and responses. Sometimes they have the good fortune of producing a creative tension in a man brave enough to attempt the synthesis of a prophet's vision with a world managed by priests.

Ibidem

Perhaps the daily reports of 'insufficient knowledge' of the effects of this or that aspect of the rape of the earth, and our sense of insufficient understanding of what our social and spiritual crises are all about, indicate that in spite of the magnificent edifice of genuine scientific knowledge bequeathed to us, we are only at the beginning of learning the things, and the ways, necessary for the human life.