On being a scientist

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Extracts from a pamphlet entitled 'On being a scientist' prepared by a committee of the US National Academy of Sciences to spell out the basic features of contemporary scientific life and the personal and professional issues that scientists encounter in the course of their work.

Frank Press, President of the US National Academy of Sciences, in his Preface, points to the great degree of personal freedom accorded to scientists: '... freedom to pursue exciting opportunities, to exchange ideas freely with other scientists, to challenge conventional knowledge. Such freedom is necessary for excellence in science, and institutions that support science safeguard them'. There is a corresponding obligation on the researcher to do science honestly and make a sincere effort to identify mistakes and correct them. Maintenance of honesty and self-correction should, therefore, be the guiding principles of the institution of science as well of the individual researcher 'who has both the capability and responsibility to maintain standards of scientific conduct'.

The exhilarating experience of a scientist is summed up beautifully:

> Moments of scientific discovery can be among the most exhilarating of a scientist's life. The desire to observe or understand what no one has ever observed or understood before is one of the forces that keep researchers rooted to their laboratory benches, climbing through the dense undergrowth of a sweltering jungle, or pursuing the threads of a difficult theoretical problem. Few discoveries seem to come in a flash; most materialize more slowly over weeks or years. Nevertheless, the process can bring great satisfaction. The pieces fit into place. The whole makes sense.

Life in science is not treading a rosy path marching from triumph to triumph without a tear. C. V. Raman, when he was praised sky-high at the celebration to mark the silver jubilee of the Raman effect, said, 'The more I look back on my career the more I feel that it has been a long history of frustration, disappointments, struggle and every kind of tribulation.' The authors of the pamphlet say:

> An experiment can fail because of a technical complication or the sheer intractability of nature. A favourite hypothesis that has consumed months of effort can turn out to be incorrect. Disputes can break out with colleagues over the validity of experimental data, the interpretation of data or credit for work done. Setbacks such as these are virtually impossible to avoid in science, and they can strain the composure of both the novice and the most self-assumed senior scientist.

Methods and limitations of science

There is no simple method in science. In practice, research is as varied as the approaches of individual researchers. 'Scientific knowledge emerges from a process that is intensely human'. How are these decisions made? How much is to be attributed to 'value-taken judgements, personal desires and even a researcher's personality'? The pamphlet first examines these points by quoting examples of the choices that scientists make in their work as individuals, the treatment of data, techniques used to minimize bias, the application of values in judging hypotheses.

Observation is shown to be the fundamental source of scientific knowledge. By gathering facts without prejudice, a scientist will eventually arrive at a correct theory. But this is not always possible. Nature is too amorphous and diverse for human beings to observe without some idea about what they are observing.

Other formulations are: (i) postulating many hypotheses and systematically setting about trying to work out the weaker ones; (ii) asking questions of nature—what would happen if...?, why is that...?; (iii) gathering a great deal of data when there are only vague ideas about the problem; (iv) developing a hypothesis or conjecture first and then trying to verify or refute it with carefully structured observations.

The pamphlet quotes Peter Medawar describing scientists as

> people of dissimilar temperaments doing different things in very different ways. Among scientists are collectors, classifiers and compulsive tidiers-up; many are detectives by temperament and many are explorers; some are artists and others artisans. There are poet-scientists and philosopher-scientists and even a few mystics.

Pitfalls in the treatment of data

One way of handling data is to use all the observations made without discrimination. The other is to use only those regarded as 'best' data sets. We are told that the Nobel Prize-winning physicist Robert Millikan adopted the second method and was criticized for not disclosing which data he omitted or why he omitted those data. The authors of the pamphlet point out that by present standards what Millikan did is not acceptable. 'Scientists', they point out, 'must be willing to acknowledge the limitations of their data if they are not to mislead others about the data's reliability'. They add:

> General rules for distinguishing *a priori* 'good' data from 'bad' cannot be formulated with clarity. Nevertheless, good scientists have methods that they can apply in judging the reliability of data, and learning these methods is one of the goals of scientific apprenticeship .... A researcher is not free to select only the data that fit his or her prior expectations. If certain data are excluded, a researcher must have justifiable reason for doing so.

This caution ought to be well taken by our scientists.

Then follows a note on the risk of self-deception:

> Awareness of the inroads that theory can make into observations serves as a valuable reminder of the constant danger of self-deception in science. Psychologists have shown that people have a tendency to see what they expect to see and fail to notice what they believe should not be there.

Self-deception can take more subtle forms. For example, a researcher may stop a data run too early because the observations conform to expectations, whereas a longer run might turn up unexpected discrepancies. Insufficient repetitions of experiments are a common cause of invalid conclusions, as are poorly controlled experiments.

Scientists have developed a vast array of methods that are designed to minimize the kinds of problems discussed above.

The fallibility of methods means that there is no cook-book approach to doing science, no formula that can be applied or machine that can be built to generate scientific knowledge. But science would not be so much fun if there were. The skilful application of methods to a challenging problem is one of the great pleasures of science. The laws of nature are not apparent in our everyday surroundings, waiting to be plucked like fruit from a tree. They are hidden and unyielding, and the difficulties of grasping them add greatly to the satisfaction of success.

Formulation of hypotheses

Many hypotheses are formulated in the course of scientific work to explain the available facts and each may suggest an alternative route for further research. How then should one make a selection out of these?

Hypotheses should be internally consistent, so that they do not guarantee contradictory conclusions. Their ability to provide accurate predictions, sometimes in areas far removed from the regional domain of the hypothesis, is viewed with great favour. ... Good hypotheses should be able to unify disparate observations. Also highly prized are simplicity and its more refined cousin, elegance.

The pamphlet illustrates how preference to a hypothesis can be governed by philosophical, religious, cultural, political and economic predilections by pointing to the case of the nineteenth century geologist Charles Lyell, one of the founders of geology and the champion of the theory of uniformitarianism, a concept which argues for incremental changes operating over long periods of time, rather than catastrophic events, to produce earth's geological features. This hypothesis is even today considered valid by many. We learn that Lyell's preference to this hypothesis was as much influenced by his religious convictions as on his geological observations.

Is holding such views harmful? Yes, declare the authors of the pamphlet. 'The history of science offers many episodes in which special or personal values led to the promulgation of wrong-headed ideas'. One glaring instance is the production of 'scientific' evidence for supremacy of the white race over the black, evidence which we now know to be wholly erroneous. These examples are offered as valuable reminders of the danger of letting values intrude into research, creating biases and distorting the results of scientific investigations.

Judging hypotheses

The pamphlet then comments on the attitude of scientists when new observations come into conflict with long-established theories. Darwin's theory of evolution is quoted as a classical example. Darwin continued to defend his theory even when Kelvin argued that the age of the earth could not be more than 100 million years taking note of the loss of heat since its birth. Darwin argued that such a time span would not have allowed the evolutionary process to operate. It was only when radioactivity was discovered and the heat generated by it had to be taken into account to revise the age of the earth that the criticism lost its force. Darwin clung to his hypothesis doggedly and was not vindicated till after his death.

At the other extreme, is the case of scientists holding on to outdated theories even after they had been discarded.

Hanging on for a while to a favourite but embattled idea is often a necessity during the initial stages of research. But scientists must also learn to give way in light of new and more insistent evidence.

Peer recognition and priority of discovery

An important motivating force in science is the desire for recognition by fellow scientists: 'One of the greatest rewards that scientists can experience is to have their work acknowledged and praised by other scientists and incorporated into their colleagues research'.

Another rule is that the first person or group to publish the results generally gets the lion's share of credit for it although another group may be working at the same problem. In fact, priority is given according to the date the paper reporting the work is received by a scientific journal.

Once published, scientific results become public property of the research community, but their use by other scientists requires that the original discoveries be recognized. Only when results have become common knowledge are scientists free to use them without attribution.

This understanding seems to have evolved only slowly. We are informed that early scientists (including Isaac Newton) were loath to convey news of their discoveries to scientific societies for fear that someone else would claim priority. It was only when Henry Oldenberg, secretary of the Royal Society, came forward to guarantee rapid publication in the Society's *Philosophical Transactions* that scientists were won over and brought round to the publication of the results of their research.

Science, therefore, does not function in isolation. 'Scientific research takes place within a broad social and historical context, which gives substance, direction and, ultimately, meaning to the work of individual scientists.

Researchers submit their observations and hypotheses to the scrutiny of others through many informal and formal mechanisms. They talk to their colleagues and supervisors in hallways and over the telephone, airing their ideas and modifying them in the light of the responses they receive. They give presentations at seminars and conferences, explaining their views to a broader but still limited circle of colleagues. They write up their results, and send them to scientific journals, which, in turn, send the papers to be scrutinized by reviewers. Finally, when a paper has been published, it is accepted or rejected by the community to the extent that it is used or ignored by other scientists.

At each stage researchers submit their work to be examined by others with the hope that it will be accepted. This process of public, systematic scepticism is critical in science. It minimizes the influence of individual subjectivity by requiring that research results be accepted by other scientists. It is also a powerful inducement for researchers to be critical of their own conclusions, because they know that their objective must be to convince their ablest colleagues, including those with contrasting views.

The publication in a peer review journal therefore is the standard means of disseminating results. Short-circuiting this self-correcting mechanism and publicizing work through a press conference risks adverse reaction later, as happened recently with the research on cold fusion.

Fraud in science

Science operates on a basis of trust and honesty among its practitioners. Scientists are not infallible and may commit errors. When such errors are discovered, they should be acknowledged. Mistakes made while trying to do one's best are tolerated, but mistakes committed through negligent work are not. There is a significant difference between preventable error and deliberate fraud.

Of all the violations of the ethos of science, fraud is the gravest as it erodes the foundation of trust on which science is built. The effects of fraud on other scientists in terms of time lost, recognition forfeited to others and feelings of 'personal betrayal' can be devastating.

There are various types of fraud, ranging from 'selecting only those data that support a hypothesis and concealing the rest' ('cooking' data) to changing the readings to meet expectations ('trimming' data) to outright fabrication of results.

An instance of alleged serious fraud is fresh in our memory. A palaeontologist has been charged with systematically taking data by 'planting' fossils. This has been widely publicized. The case has served to demonstrate how the in-built safeguards in scientific method and procedure help uncover fraud.

Science could not be the successful institution it is if fraud were common. The social mechanism of science, and in particular the sceptical review and verification of published work, acts to minimize the occurrence of fraud.

Whenever serious allegations are made and prima facie case of alleged fraud established, the incumbent should be suspended from his duties and a committee constituted to review the reliability of his scientific work. Such corrective action will go a long way in reducing the incidence of fraud. Assaults on the integrity of science can be damaging and must be speedily corrected.

The allocation of credit

The importance of allocation of credit and responsibility between authors and those engaged in similar work, and the purpose served by citations are considered. Citations serve a number of purposes in a scientific paper. They acknowledge the work of other scientists, direct the readers towards additional sources of information, acknowledge conflict with others' results and provide support for the views expressed in the paper. More broadly, citations place a paper within the scientific context, relating it to the state of knowledge of its area. The pamphlet contains this beautiful quotation from Robert Merton:

We thus begin to see that the institutionalized practice of citations and references in the sphere of learning is not a trivial matter. While many a general reader—that is, the lay reader located outside the domain of science and scholarship—may regard the lowly footnote or the remote endnote or the bibliographic parenthesis as a dispensable nuisance, it can be argued that these are in truth central to the incentive system and an underlying sense of distributive justice that do much to energize the advancement of knowledge.

The authors of the pamphlet say it is impossible to provide a set of rules that would guarantee the proper allocation of credit in citations. They only emphasize the obligation scientists have in giving others the credit they deserve.

Scientists who expect to be treated fairly by others must treat others fairly.... Science will function most effectively if those who participate in it feel that they are getting the credit they deserve. One reason why science works as well as it does is that it is organized so that natural human motivations, such as the desire to be acknowledged for one's achievements, contribute to the overall goals of the profession.

The apportioning of credit between senior and junior authors can be a bone of serious contention. While there can be no defence for the practice of 'honorary authorship', by which the head of the institution or laboratory affixes his name invariably to all papers emanating from the laboratory, the need to encourage a research assistant taking his first steps in science appears paramount.

Senior scientists are well aware of the importance of credit in the reward system of science, and junior researchers cannot be expected to provide unacknowledged labour if they are acting as scientific partners. In such cases, junior researchers may be listed as coauthors or even senior authors, depending on the work, tradition within the field, and arrangement within the team.

The evil of plagiarism is characterized as 'the most blatant form of misappropriation of credit'. 'This may range from obvious theft to uncredited paraphrasing that some may not consider dishonest at all'. The pamphlet counsels that 'erring on the side of excess generosity in attribution is best'.

The human face of science

The authors plead that scientists

should not disguise the human factors that motivate and sustain research as the value judgements that inevitably influence science. They should explain and defend the scientific world view, a prospect of great beauty and grandeur that ought to be a part of how people think about themselves and their place in nature. Scientific research is an intensely human endeavour. This humanity must not be lost in the face science presents to the world.

The pamphlet ends with an extract from Einstein placing the whole discussion in its true perspective:

Concern for man himself and his fate must always form the chief interest of all technical endeavours . . . in order that the creations of our minds shall be a blessing and not a curse to mankind. Never forget this in the midst of your diagrams and equations.

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