Chapter 2
It's About Attitude and Experiments

Abstract Although it is clear that philosophers are unable to identify unique methodological elements that characterize scientific research, it appears that we can identify certain features from which it derives its explanatory power. An awareness of the philosophical and historical underpinnings of science provides the researcher with the conceptual and analytical tools to examine and evaluate his practice. These tools will also help in the assessment of the work done in his own field, and in other disciplines.

> You look at science (or at least talk of it) as some sort of demoralising invention of man, something apart from real life, and which must be cautiously guarded and kept separate from everyday existence. But science and everyday life cannot and should not be separated. Science, for me, gives a partial explanation for life. In so far as it goes, it is based on fact, experience and experiment.
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> Rosalind Franklin (1920–1958).

There can be no serious doubt about the success of modern science in describing and understanding the physical world. The remarkable increase in scientific knowledge since the time of Galileo has been at the root of a technological revolution that has transformed the way we live. It takes only a moment of reflection on the impact of scientifically based improvements in the fields of engineering, medicine, dentistry, transport, and communications to make this clear and undeniable.

The achievements of the scientific program have inevitably stimulated questions about why science has been so successful. The enterprise of scientific research seems to be invested with a special status in which scientists are accorded particular respect because of their access to technological knowledge and the power that derives from it. On the face of it, there would appear to be something special about science that distinguishes it from other forms of inquiry, and much effort and thought has been directed towards identifying and understanding its distinguishing features. The assumption has been that science is characterized by a "method" that allows it to arrive at descriptions of the natural world which have a uniquely powerful explanatory and predictive power.

P. Truran, *Practical Applications of the Philosophy of Science*,
SpringerBriefs in Philosophy, DOI: 10.1007/978-3-319-00452-5_2,

For the last four hundred years, philosophers have attempted to elucidate the nature of scientific method. They have tried to construct clear, logical pictures of the way science works to deliver reliable knowledge. However, studies in the history of science and of current scientific practice reveal a complex reality marked by disciplinary peculiarities and pluralistic approaches. Science is, indeed, a messy business. Every attempt to provide a rigorous basis for distinguishing science from non-science, or to provide a description of scientific method which would be embraced by the community of researchers, has ultimately foundered. Indeed, the project to find an acceptable, universal description of scientific method is probably doomed to failure. While a minority of scientists acknowledges a correspondence between the descriptions provided by philosophers with the realities of their own research practice, most researchers pay scant attention to such explanations. However, although the philosophy of science may never succeed in pinning down what scientists actually do, it can provide researchers with more effective and accurate ways of talking about their work. Furthermore, it can tell them what they should do in order to be better scientists. In other words, it can provide researchers with "normative" advice. And that advice will be more pertinent if researchers engage with philosophers in the debate about what they should do and what they actually do.

Not all science is good science. It is easy to point to gross examples such as the ideologically driven application of Lamarck's theory of the inheritance of acquired characteristics, by the Russian pseudoscientist Trofin Lysenko, which contributed to ruinous agricultural practices during the Stalinist era in the Soviet Union. However, poor scientific practice is also at the root of the studies in the 1990's which provided the basis for arguments against the use of childhood vaccinations for whooping cough, the Cold Fusion debacle, or the withdrawal from the market of numerous pharmaceuticals which were shown to have serious, sometimes lethal, side-effects. In a report published in 2005 (Ioannidis 2005) it was estimated that more than 50% of research findings could not be relied upon because of small sample sizes, poor study design, researcher bias, selective reporting and other problems. Although some bad science may be the result of deliberate deception driven by commercial pressure or personal ambition, much of it is rooted in a faulty understanding of the nature of science.

It is evident that researchers who declare that they know nothing of the philosophy of science may, in reality, talk in philosophical terms about what they do. There is always an ongoing debate about the methods of science, about ethical issues related to the use and misuse of science, about its truth status and about issues such as the validity of Intelligent Design, or the causes of global warming. Furthermore, the ways in which scientists articulate and reflect upon their practice will affect, to some degree, what they do in their research. This is an important point. For example, the researcher who describes gathering data before formulating the solution to a problem may not actually be doing this in practice. He is most likely to be making observations in the light of a hypothesis that he has not explicitly formulated or "spelled out". If this is the case, the quality and number of observations may be compromised. The researcher's understanding about what he is doing *as a scientist* may therefore affect the quality of the research being done. The normative prescriptions of the philosophers of science can help the well-intentioned scientist to avoid pitfalls and improve research practice.

Such principles and prescriptions will always have their shortcomings. They may be more appropriate in one research context than another and may fall short in terms of their general applicability. However, they provide a framework, to be continuously and critically reviewed, for the ways in which the scientist may proceed. Generally, it is in the work of those philosophers of science (such as Popper and Kuhn) who have been embraced and recognized by the scientific community that we find an expression of those principles that are likely to be most useful and pertinent to the researcher.

Although philosophers are unable to identify unique methodological elements that characterize scientific research, they can identify certain features from which it derives its explanatory power. These "normative" principles may be summarized as follows:

1. Science is a system of methods for solving problems.
2. Science is characterized by an *attitude* that values intellectual honesty, integrity and open-mindedness, and exhibits a measured skepticism which embraces criticism and rejects dogmatism. It does not accept explanations that make reference to miracles or the supernatural. All scientific knowledge is regarded as provisional. This attitude is not confined to science, and it may be found as a core doctrine within many other disciplines, for example philosophy.
3. Science is rational. It employs agreed methods of reasoning that allow reliable connections to be made between supporting information and the conclusions to be derived from that evidence. Note that good reasoning does not assure the truth of conclusions since these may be based upon supporting information that is false. Although these methods of reasoning are characteristic of science, they are applicable within other areas of knowledge that may not immediately be considered to be scientific.
4. Science uses *experiments*, investigations or studies to test solutions to problems. Experiments allow us make and test predictions about the behavior of the physical world, and to establish consistent, repeatable ways of interacting with it.

Experiments are the practical embodiment of the critical and skeptical attitudes which are at the core of scientific methodology, an attitude which continually asks, "Might my current explanation be mistaken?" and "Is there, perhaps, an alternative explanation?" Experimentation has become the standard instrument in mainstream science for revealing the errors present in our ideas and for comparing and choosing between different solutions to problems (Mayo 1996). It has become the means for establishing the scientific credibility of disciplines as diverse as sociology, economics, anthropology and psychology.

The key and defining characteristic of an experiment is that it should be a genuine test of the solution to a problem. It is crucial that an experimental test should be set up and conducted in such a way that there is a possibility that the results of the experiment could indicate that the proposed solution is wrong or false. There is no point in doing a "test" on an idea that you know will always confirm that idea, no matter the outcome of the test. The researcher therefore, frames the proposed solutions to scientific problems (or hypotheses) so that they are considered to be "falsifiable", although we shall see that the concept of falsifiability has its own problems. Nevertheless, the aim of the good researcher is to establish experiments that are severe tests of the solutions under consideration. The more severe the test which is passed, the more confidence the researcher can have in the proposed solution.

The concept of "falsifiability" was proposed by Popper (1963) as a logical criterion for distinguishing scientific propositions from non-scientific or "metaphysical" ones. Scientific ideas would be subjected to empirical tests in which they would run the risk of falsification and rejection. Popper was particularly impressed by the case of Einstein's Theory of General Relativity which was subjected to a severe and definitive test in the famous experiment carried out by Arthur Eddington in 1919. Eddington and his team demonstrated during a solar eclipse that light from stars that appeared close to the sun was deviated by the effect of the mass of the sun, a novel prediction derived from Einstein's theory. If the light had not deviated by the amount predicted according to the theory of General Relativity then, in principle, Einstein's theory would have been falsified.

Nevertheless, it was recognized by Popper that, if Einstein's theory had not passed the test of Eddington's experiment, this would not in itself have been a decisive blow against Einstein's theory. Philosophers and scientists agree that, even if an idea or solution fails an experimental test, this may not enough to reject it. The solution we have may be the best we have so far, and there may be no viable alternative. There may be doubts about the instrumentation used to carry out the experiment, or the experiment itself may be flawed. This was certainly the case in Eddington's experiment where some of the results obtained were shown to be anomalous because of problems with one of the telescopes used. For many years, there were serious concerns about the validity of Eddington's results. What is clear, however, is that the scientific attitude requires the scientific researcher to employ all the logical and critical faculties at his disposal in order to carry out tests which are as fair and severe as possible, recognizing that, even then, the results may be misleading or plain wrong. All solutions to scientific problems, all scientific knowledge, are in this sense provisional.

Note that, in some research disciplines, it is not possible to conduct experiments to test hypotheses. This is the case in the so-called historical sciences, among which we can name archeology, paleontology, geology, and cosmology. It is simply not possible to manipulate conditions to test ideas about the origin of the universe or the extinction of the dinosaurs. Instead, much of the research effort in the historical sciences is based upon *counterfactual reasoning* which asks the question "What might be *not* be found if a particular event had not occurred?" As such, inquiries are often directed towards the search for a "smoking gun" that will support the acceptance of a hypothesis (but not eliminate competing hypotheses). A good example of a "smoking gun" is the three-centimeter background radiation that was predicted to exist as a result of the Big Bang. Another is the discovery of iridium and shocked quartz in the Cretaceous-Tertiary boundary that provided evidence of the meteor impact that is believed to have caused the extinction of the dinosaurs sixty five million years ago. If an asteroid impact big enough to cause climate change had *not* occurred, then the observed geological evidence would not be found. These differences in the means used for testing hypotheses in the historical sciences do not reduce their credibility or scientific status (Cleland 2001).

If we characterize scientific methodology as comprising the deployment of a scientific attitude together with the rigorous testing of hypotheses, then it has wide applicability outside of mainstream science. The application of scientific methodology is appropriate whenever, we require our interactions with the physical world to be predictable and replicable. This is clearly the prime concern of the physical scientist who is elucidating the laws that describe and explain phenomena in the natural world. However, when we survey the range of research disciplines, it is clear that the applicability of scientific methodology, and especially the testing of hypotheses, is much wider than we might first anticipate.

As in the natural sciences, we see within the humanities the expression of values—intellectual honesty, open-mindedness and non-dogmatic skepticism—which are key features of the scientific attitude. Nevertheless, the humanities are not generally considered part of the scientific endeavor because they generate problems that cannot be resolved by the use of experimental testing. However, within a number of disciplines in the humanities, for example theology and history, there are areas where the application of scientific methodology is clearly appropriate. We would not usually describe the field of biblical exegesis (the understanding and interpretation of biblical texts) as scientific. However, academic studies which treat the bible as a historical document use a number of approaches which may be regarded as scientific, for example the techniques of textual analysis used to identify the authors of the book of Genesis. Similarly, the fundamental questions posed by historians will never be amenable to resolution by scientific research methodology precisely because historical events cannot be repeated under experimental conditions. However, the use of chemical analyses, carbon dating, DNA analysis and MRI scans have all proved to be important tools for the historian, and the application of these techniques may be done within a context which is purely experimental.

This characterization of science as dependent on the rigorous testing of hypotheses allows us to view activities that took place in the pre-scientific age as being within the scientific tradition. Consider the achievements of the Greeks who developed lead sheathing of ships to protect their hulls, air and water pumps, and the truss roof. The Romans developed concrete, built the dome of the Pantheon, still the largest unreinforced concrete dome in the world, and constructed sophisticated systems of aqueducts. These were the result of processes of trial and error that meet all the requirements for being considered scientific. Whenever practical utility is important in the assessment of a conceptual development, the processes are likely to exhibit the features that characterize modern science. There can be no place for dogmatism or a rejection of test results in the area of ship design or in the construction of large stone buildings. When a ship sinks, or a building collapses, the outcome of the test is beyond dispute. The differences between modern science and that which took place in the "pre-scientific" age are primarily ones of rigor and organization, especially the documentation of theories and the experiments used to test them, and the establishment of institutions for discussion, critique and review of scientific ideas and developments. It is also clear that the success of modern science is attributable in large part to the elimination of supernatural explanations from the process of scientific inquiry. The processes of trial and error that underlay much pre-scientific technological development were confounded by the need to satisfy religious traditions or the demands of supernatural forces.

> The whole of science is nothing more than a refinement of everyday thinking.
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> Albert Einstein (1879–1955).

An awareness of the philosophical and historical underpinnings of science provides the researcher with the conceptual and analytical tools to examine and evaluate his practice. These tools will also help in the assessment of the work done in his own field, and in other disciplines. It is no longer acceptable to reject research in the historical sciences as unscientific. Indeed, we now recognize that the attitudes and methods of the sciences are ubiquitous, and will be found within many disciplines that we would not otherwise consider primarily scientific. The borders between science and non-science are therefore not clearly marked. However, a clear understanding of the distinguishing features of science will help us to make appropriate judgments about the scientific status of research findings and claims. It will also allow us to identify when it is appropriate to apply the methods of the sciences to our problems and when it is not.

Practical Points

- Take time to step back and think about what you are doing as a researcher. A judicious study of many of the ideas and concepts that form the basis of the philosophy of science will improve your reasoning skills and clarify your approach to your research.
- Develop a non-dogmatic skepticism of the ideas and data that are presented to you, but do not let your criticism be unnecessarily destructive. Be fair in your criticism, and supportive and constructive whenever you can. A reputation for being negative will harm your ability to work with others and may deprive you of support when you most need it.
- Make a point of learning about designed experiments and statistics, and the ways they may be used to study those aspects of the world that can be controlled and measured. Experiments are the classical tools of science, and can bring order and clarity into our interactions with the natural world.

- Ensure that your experiments represent genuine tests of your hypotheses. Stipulate clearly the results and outcomes that would constitute evidence against the hypothesis you are testing.
- If we cannot carry out experiments that would involve the manipulation and control of key variables, then we must ensure that we provide reasoned evidence that supports our hypotheses. This will generally be less definitive than the results of a well-designed experiment.
- Scientific thinking is not solely the province of scientists. We can cultivate an attitude that embraces intellectual honesty, open-mindedness and measured skepticism, and a willingness to subject ideas to rigorous testing in all knowledge disciplines and in all walks of life.
- We can make judgments about when it is appropriate to apply scientific thinking and experimental method to our problems, whether these occur in our professional work as researchers or as part of our daily lives. Sometimes, it may simply not be worth the effort—the problem may be just too trivial. Simple trial and error may suffice. At other times the problem may require the application of the full rigor of the scientific methodology. And then there are the times when we need to abandon the analytical perspective of the scientist—to simply look at the full moon on a still cold winter's night and wonder at its beauty. We need to know when to be poets and when to be scientists. A better understanding of science will allow us to make these judgments more clearly.

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http://www.springer.com/978-3-319-00451-8

Practical Applications of the Philosophy of Science
Thinking about Research
Truran, P.
2013, X, 102 p., Softcover
ISBN: 978-3-319-00451-8