THE VALUE OF A SCIENTIFIC WORLDVIEW

"SCIENCE IS A WAY OF THINKING, MUCH MORE THAN IT IS A BODY OF KNOWLEDGE."

– Carl Sagan, American astronomer and science communicator

Text: Ian Seldrup

Science has been driving human civilisation for centuries. The sciences – and their close cousin, engineering – have been responsible for progress in every facet of our lives. From the earliest thinkers of ancient Greece, Egypt, China and Arabia to the multinational teams tackling the greatest challenges of the 21st century, scientists and engineers have changed the way we live, work, travel and communicate – the very way we think and how we view ourselves and our place in the universe.

The history of science is flush with examples of great men and women whose scientific work is of such significance that it has become part of our collective cultural heritage. Galileo, Newton, Darwin, Pasteur, Curie, Einstein, Freud – these pivotal figures, and countless others, have shaped our understanding of the cosmos, the planet, the particles that constitute matter, the human body and the mind, the origins of life itself.

Much more than just generating abstract ideas, science is responsible for laying the foundations of our tangible modern world. From the Industrial Revolution of the 18th century to the Digital Revolution of the present day, the achievements of science and engineering have been manifested in the technologies that surround us. From steamships and automobiles to industrial robots and the World Wide Web – everything has roots in the scientific endeavour, with innovation drawing on an ever-broadening, ever-deepening spectrum of knowledge in a vast number of different fields.

But if the scientific enterprise is so uniquely successful, what exactly makes it special? Are there some basic perspectives and motivations behind every scientific mind? How does someone without scientific training begin to think more scientifically? And whilst we're developing our scientific view of the world, what do we do with any beliefs and traditions that don't seem to fit?

The scientific community encompasses a large cross-section of people working in both academia and industry: the physicists and chemists of the "physical sciences"; the ecologists, geologists and oceanographers of the "earth sciences"; the botanists, biologists and zoologists of the "life sciences"; the computer scientists, statisticians and mathematicians of the so-called "formal sciences", among many others. But whatever discipline they belong to, when it comes to their work, scientists of every stripe have certain shared views and methods. These beliefs and assumptions about the world are what define scientists, provide guidance in what they do, and allow them to work collaboratively and with similar aims in mind. But what makes up the "scientific worldview"?

First and foremost, scientists see order in the apparent chaos of Nature. They believe that by carefully and systematically studying patterns of behaviour, a comprehensible and consistent picture will emerge, where laws and principles that describe one part of the world can be applied to similar situations elsewhere. From the scientific viewpoint, even if some natural phenomenon cannot be adequately explained – or even if there is *never* an adequate explanation – it can still, *in principle*, be explained. The limits of our intellect and ingenuity are the only real obstacles to overcome in creating knowledge about the universe.

Second, scientists appreciate that by studying the world and coming up with scientific explanations for observed phenomena, there is always a possibility that those explanations may change – or even be completely wrong. This goes to the heart of the scientific endeavour: what scientists think they know may need to be modified if new observations come to light that are not well explained or if another explanation fits the observations better. For this reason, an explanation that can be shown to fit the data, reliably and consistently, is referred to as a *theory*. Scientific theories can and do change – this is an expected and accepted part of science.

The third and final pillar of the scientific worldview is an admission about the limitations of science. The nature of the scientific enterprise means that there are many things that simply can't be treated scientifically. Every natural phenomenon

DID YOU KNOW? THE SCIENTIFIC METHOD

The procedure used for scientific enquiry is referred to as the *scientific method*. It's most easily formulated as a series of distinct steps, but in practice different situations and different scientific disciplines may require additional steps, the steps to be followed in a different order, or more or less emphasis on some steps than on others. Ultimately, though, the method attempts to build knowledge about the world in a consistent, reliable and reasoned fashion – in line with the scientific worldview. Here's a typical formulation of the steps:

DESCRIPTION: Observe and describe a phenomenon or phenomena.

HYPOTHESIS: Formulate a hypothesis to explain the phenomena.

PREDICTION: Use the hypothesis to predict the results of new observations, or the existence of other phenomena.

TESTING: Determine whether the predictions are correct by carefully carrying out experiments.

ANALYSIS: Examine the results of experiments, establishing whether the experimental evidence is strong enough to support the hypothesis. If it isn't, consider what to do next, such as testing other predictions from the hypothesis, or formulating a new hypothesis.

Experimental measurement can never be perfectly precise. (Indeed, for scientists, it's of no value to give a measurement without quoting the experimental error.) Therefore, an essential component of science is minimising systematic errors that could lead to false conclusions. In the history of science, there have been many examples of systematic errors being the real cause of "great new discoveries". Equally, true discoveries have also been overlooked when scientists have dismissed important systematic "background" data.

might have a scientific explanation (even if *current* scientific knowledge is inadequate to explain it), but scientific methods cannot, for example, be used to decide what is right and wrong, predict whether you'll win the lottery next week, or verify that Jesus performed miracles.

At its best then, the scientist's worldview has many merits: it is rational and questioning, it strives for the continual refinement of knowledge and is always open to challenges, and it does not claim to provide answers to every problem.

THINKING LIKE A SCIENTIST

Albert Einstein once said: "I have no special talents. I am only passionately curious." Certainly, the theoretical physicist's passion and curiosity cannot be faulted, but concerning his gifts he was surely being too modest. Every great scientist, indeed any good scientist, shares certain skills and abilities that enable them to undertake their work. As well, although scientists from different disciplines differ in the details of how they go about their work, there is agreement within the community about what makes an investigation scientific (*see box on previous page*: The Scientific Method). These general characteristics of scientific enquiry are utilised by working scientists of all disciplines, but they can just as usefully be employed by anyone interested in thinking more like a scientist when tackling day-to-day problems.

1 **Logically imaginative:** Firstly, and above all, science requires a certain combination of creativity and logic. Even the most far-fetched scientific ideas must be developed using logical, rational and common-sense arguments where conclusions follow from the assumptions made and the evidence gathered. Scientific ideas that fail on this logical level – however creative they are – will eventually be picked apart by other scientists.

Imagination alone is not enough – this is what sets science apart from science fiction. Charles Darwin's theory of evolution by natural selection may seem intuitively obvious today, but in the mid-19th century when the theory was published – well before the word "gene" had been invented – his idea was a brilliant stroke of invention. More than that, however, his theory was presented using clear, reasoned arguments and supported by years of carefully collected evidence.

2 **Evidence-based:** The need for solid evidence to back up any scientific claim is the second aspect of scientific enquiry. Without properly collected data to support it, whether obtained through passive observation of a natural phenomenon or by carefully setting up experiments in a laboratory, a scientific idea cannot be tested. This gathering of data can be as straightforward as collecting things, such as fossils or beetles, to demonstrate patterns, or as complex as conducting a clinical trial to determine the dose of a new drug.

The value scientists place on evidence means not just that experimental procedures must be very precisely applied, that conditions must be carefully controlled and techniques constantly improved, but also that the instruments used to collect data – from the humble optical microscope to the massive radio telescopes that probe deep space – must produce accurate, high-quality results. A scientific theory has to stand up to scrutiny, so the evidence gathered to support the theory must be sound and reproducible by others.

3 **Predictive:** Since a given theory can only be supported by a finite amount of evidence, a valuable scientific theory must also be able to predict relevant observations that are yet to be made. A theory's power to predict doesn't only refer to future events: evidence from past events that is uncovered must also be encompassed by a valid theory.

A good example is what would later be called the "Big Bang Theory", but what began as Georges Lemaître's 1927 proposal that the universe expanded from a "primeval atom". Although the theory brilliantly explained various outstanding cosmological problems of the time, scientists as accomplished as Fred Hoyle and Albert Einstein refused to take it seriously. Then, in 1948, Robert Herman and Ralph Alpher made a crucial prediction: if the Big Bang Theory was correct, the explosion would leave behind a "heat signature" that could, in principle, be measured. When this distant echo of the Big Bang – the cosmic microwave background radiation – was discovered in 1964, a significant majority of the cosmological community was quickly on-board.

The development of the Big Bang Theory is typical of the way many scientific theories take form: a series of interrelated and layered ideas, each building on the demonstrated success of others, and each supported by a gradually widening, more persuasive body of evidence.

4 **Unbiased:** While the requirement of logic, supporting evidence and predictive power in scientific enquiry sounds highly compelling, it's unsafe to assume that the people that conduct their science around these principles are infallible. All good scientists are aware of the possibility of bias being introduced into measurements, or in the interpretation of results, or even in deciding what should or should not be studied. Ethnicity, nationality, age, gender, politics and religious beliefs can all play a part in influencing a scientist's choices, interpretations and conclusions. And, of course, aside from unintended

DID YOU KNOW? BLIND SCIENCE

Removing bias is a hallmark of good science. Careful measures need to be taken to design experiments that avoid introducing bias, particularly where human subjects are involved. For instance, a clinical trial must be designed to eliminate all sources of bias if the effectiveness of a new medicine is to be shown. This is an example of where "blinded" approaches to experimentation are crucial. In a blinded experiment, either the subjects of the experiment or those administering the experiment, or both, are not made aware of any information about the experiment that could lead to biased results.

In a randomised double-blind experiment, a common approach in medicine, both the experimenter and the test subjects are blinded. In such clinical trials, patients are randomly assigned to the drug under investigation and a control drug – either an established drug or a placebo (a dummy treatment with no therapeutic effect) – and neither researchers nor patients know which patient is receiving which drug. Both drugs are prepared so that they cannot be distinguished; for instance, they have the same taste and appearance.

But what kinds of bias are avoided by designing a clinical study in this way? In the researcher's case, for example, if it were known that the new drug had undesirable side effects, a doctor might have (subconsciously) avoided giving frailer patients the new treatment, instead assigning them to the control drug. In the patient's case, if they knew they were receiving the new drug rather than the dummy drug, for example, their faith in the new drug might have made them feel better – the placebo effect – even if the drug wasn't actually effective. Situations such as these would unfairly distort the results of a trial.

"Nothing has such power to broaden the mind as the ability to investigate systematically and truly all that comes under thy observation in life." – Marcus Aurelius

"I am among those who think that science has great beauty. A scientist in his laboratory is not only a technician: he is also a child placed before natural phenomena which impress him like a fairy tale." – Marie Curie

"What is a scientist after all? It is a curious man looking through a keyhole, the keyhole of Nature, trying to know what's going on." – Jacques Yves Cousteau"

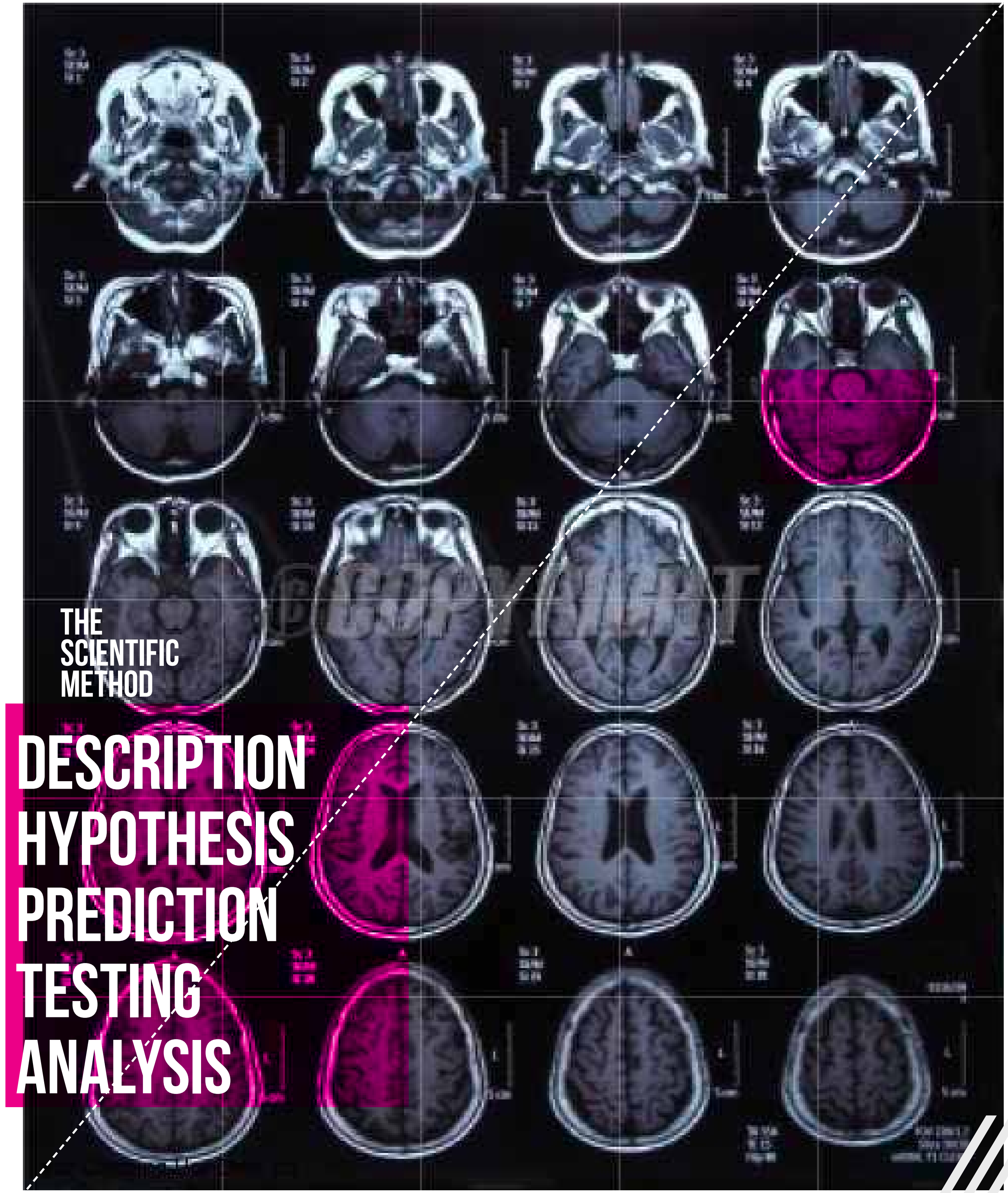
Science is the great antidote to the poison of enthusiasm and superstition." – Adam Smith

"The whole of science is nothing more than a refinement of everyday thinking." – Albert Einstein or unconscious bias, there is also the possibility that results might be falsified intentionally. Eliminating bias is an essential component of the scientific enterprise (*see box on previous page*: Blind Science).

It is often said that the beauty of the scientific endeavour is that it is "self-correcting", largely because different scientists all over world are constantly examining the evidence supporting scientific claims. In other words, given enough time, errors or biases – unintentional or otherwise – will eventually be identified and corrected. In practice, while this picture seems rosy, it can take a long time to unearth such flaws in scientific research – years, not months (which is cold comfort, for instance, for patients taking medication based on the merits of a flawed drug trial).

These core characteristics of scientific thinking are encompassed by what philosophers call "critical thinking", which applies to everyday problem-solving more generally: identifying problems, gathering evidence by observing and interpreting data, drawing logical conclusions and testing them, and so on. In all spheres of life, not just in science, critical thinking can lead to rich life experiences and to a satisfying broadening of knowledge about, and understanding of, the world.

But applying critical thinking of the kind used by scientists demands following evidence to logical conclusions – however challenging they may be to one's traditions and beliefs. Committed critical thinkers remain open-minded but have a sceptical attitude towards ideas that are not backed up by evidence; they raise clearly formulated questions rather than take unsubstantiated claims at face value; they identify biases and prejudices in themselves and others, and ensure that any assumptions are reasonable and logically sound.



SO WHAT'S YOUR WORLDVIEW?

A purely scientific worldview, using solely scientific reasoning, is an unlikely fit for anyone who needs to include values, morals, traditions and beliefs in their worldview – and, to a greater or lesser extent, that means everyone. While the principles of the scientific method are useful for solving not just scientific problems but also certain problems in everyday experience, there are instances where these principles cannot be applied.

With this limitation in mind, even scientists need to adjust their view of the world to accommodate such ideas, accepting that there is a place in their worldview for *non*-scientific matters (like morality), which do not contradict science, as well as addressing *un*scientific matters (like horoscopes), and decide whether they should or should not belong.

For many scientists and non-scientists alike, the greatest challenge of all is resolving the apparent conflict between science and faith. Even the world's top scientists – despite, or perhaps even because of, years of scientific endeavour – find a personal worldview that accommodates the notion of a Creator. And naturally, many scientists find the evidence against the existence of God too compelling to ignore.

For the rest of us, caught up in our own lives, appreciating scientific ideas can be an intimidating prospect. After the passage of several hundred years of scientific thinking, anyone who wants to make informed choices about what to accept and what to reject in their worldview surely cannot do so without looking carefully at the arguments and examining the evidence. The scientists would not want you to blindly follow them – that would be unscientific. TR