

POSTSCRIPT

Science and scientists in our time

Albert Einstein is probably the most quoted (and misquoted) scientist in history. The website Wikiquote has many more entries for him than for Aristotle, Galileo Galilei, Isaac Newton, Charles Darwin, Marie Curie or Stephen Hawking, and even for Einstein's opinionated contemporaries Winston Churchill and George Bernard Shaw.

I therefore make no apology for revisiting an Einstein comment (quoted in the introduction to 'Inside the Atom') that is highly relevant to 21st-century science, at the close of this book about five centuries of key scientists: 'Science is not and never will be a closed book. Every important advance brings new questions. Every development reveals, in the long run, new and deeper difficulties.' This dates from 1938, in Einstein's first book for a lay readership, *The Evolution of Physics*, a collaboration between the German-speaking genius and Leopold Infeld, a fellow physicist who was fluent in English.

In physics, Einstein's theory of relativity and the quantum theory developed by Einstein, Niels Bohr, Werner Heisenberg, Erwin Schrödinger and many subsequent physicists certainly raised 'new questions' and required more specialized knowledge to comprehend than, say, Newton's theory of motion and gravity and Michael Faraday's theory of electricity and magnetism. Even Einstein experienced 'new and deeper difficulties' with one of general relativity's key astronomical predictions. The black hole was an idea first proposed as a 'dark star' by the natural philosopher (and clergyman) John Michell as early as 1783, based on Newtonian mechanics. Yet for Einstein, this theoretical concept – a sharply curved four-dimensional structure precisely delineated by his equations – was too bizarre to accept. He controversially repudiated the black hole's existence in a famous paper of 1939, published by the leading US mathematical journal *Annals*

of *Mathematics*, and continued to do so until his death in 1955, for reasons he never fully explained. Not until 2017 was a black hole directly observed, by the Event Horizon Telescope, and a sensational image of it published two years later. In 2020, mathematical physicist Roger Penrose shared the Nobel prize for ‘the discovery that black hole formation is a robust prediction of the general theory of relativity’.

Since Einstein’s time, in response to the increasing complexity of science he predicted, most researchers have felt obliged to become more specialized. Far fewer now embrace several disciplines like the polymath Thomas Young, the naturalist, geologist and biologist Charles Darwin and the climatologist, geologist, geophysicist, meteorologist and polar researcher Alfred Wegener. Instead, modern researchers choose to collaborate with other specialists more extensively, by forming large groups often known as ‘research clusters’. Scientific advances in the 21st century are therefore less the product of solitary individuals than in the past, when many scientists worked almost alone – epitomized by the self-isolating Newton in his Cambridge college rooms or the youthful Einstein in Switzerland. Today, it is common for a scientific paper in a journal such as *Nature*, *Science* or *The Lancet* to be credited to a dozen (and frequently many more) authors, each contributing his or her limited expertise, rather than being authored by one or two scientists, as was generally true of Einstein’s published papers.

Consider the following celebrated examples of current science, too recent to have been covered by this book, which is deliberately restricted to deceased scientists (apart from Francis Crick’s collaborator James Watson):

1. The exploration of space, inaugurated by the *Sputnik* satellite in 1957 and typified by the Hubble Space Telescope launched in 1990, has been organized by national and international agencies, most notably the space agency NASA, not by individual scientists.

2. Global research in climate science has been developed by the United Nations’ Intergovernmental Panel on Climate Change founded in 1988 – unlike the first accurate monitoring of increasing atmospheric carbon dioxide from 1958, the origin of the Keeling Curve, which was devised by a single scientist, the geochemist Charles David Keeling.
3. The development of the internet in the 1990s was the work of a large group: the World Wide Web Consortium, today counting over 450 member organizations – unlike the development of the digital computer by Alan Turing and, separately, John von Neumann from the 1930s to the 1950s.
4. The draft sequence of the human genome announced in 2000 was the work of another group: the Human Genome Project, involving 20 major institutions, companies and laboratories – in contrast with the discovery of DNA’s structure by Rosalind Franklin, Crick and Watson in the early 1950s.
5. The elementary particle known as the Higgs boson that supports the current Standard Model of particle physics was discovered by the multinational Large Hadron Collider project at the CERN laboratory in 2012 – not by the theoretical physicist Peter Higgs, who predicted its existence in 1964.
6. During the worldwide pandemic beginning in 2020, the names of pharmaceutical companies have dominated the news, rather than the names of the many epidemiologists researching and testing COVID-19 vaccines – unlike earlier breakthroughs such as the rabies vaccine devised by the chemist and microbiologist Louis Pasteur in 1855 and the polio vaccine developed by the virologist Jonas Salk in 1955.

That said, outstanding individuals unquestionably remain pivotal to scientific progress, as indicated by the annual award of Nobel prizes in chemistry, physics and physiology or medicine, which are still restricted to a maximum of three scientists per award and never given to large research groups. The computer scientist Tim Berners-Lee, who founded the World Wide Web Consortium in 1994, was key to the development of the internet, as was the biotechnologist Craig Venter to the sequencing of the human genome, and the Keeling Curve of rising carbon dioxide concentration to the understanding of climate change. But whether such scientists of our time belong in the same league as Turing, Crick and Wegener is still uncertain. It is too soon to be sure of their long-term status – not least because some, such as Berners-Lee (who received the Turing Award for inventing the World Wide Web in 2016), are still active researchers. However, of one thing we may probably be certain: all of the greatest scientists, past and present, would agree with Newton's verdict on how he derived his most famous scientific achievement: 'By thinking on it continually.'