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Does science get the credit for too much?

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Abstract

Engineering and technology have traditionally been included under the rubric of "applied science," but this has been questioned in recent scholarship, which has drawn attention to the independence of these. They are typically not at all mere applications of science but in many cases motivate scientific enquiry. I draw attention to the criticisms of the "applied science" model that have been raised, and ask what consequences this has for our understanding of science.[1]

Introduction

At the end of the nineteenth century, science was considered to lie at basis of the progressive enhancement of civilization: railways, piped water, sewerage systems, steam-powered shipping, better food, warmer homes, softer clothing, and the massive transformation of domestic life and working hours brought about by the introduction of gas and electric lighting. But was it science as such that delivered the goods? When people thought about the benefits of modernity, for example, what they thought about were technological and medical achievements affecting the domestic and working environment, not an increase in the theoretical understanding of natural processes.

What is the connection between the two? The traditional answer is that technology is simply "applied science." There is "pure science," the search after truth, and the by-products of this, practices wholly dependent on it. Consider the statement (1956) of the historian of science George Sarton, for whom "the chief aim of scientific research is not to help mankind in the ordinary sense, but to make the contemplation of truth more easy and more complete,"[2] or that by Charles Eliot, president of Harvard University from 1869–1909, when he claimed that the goal of science had nothing to do with its practical applications, but the fact that science "enables and purifies the mind."[3] "Purity," of course, needs to be protected. When the Regius Chair in Civil Engineering and Mechanics was instituted at Glasgow in 1840, there was staunch opposition to the subject from the professors of natural philosophy and mathematics, who argued that any theoretical questions were exclusively theirs, and that practical skills could be taught outside the university through the apprenticeship system. The chemistry professor was particularly obstructive and managed, as a matter of principle, to prevent

1 Emeritus Professor Stephen Wallace Gaukroger died on 3rd September, 2023. Stephen Gaukroger won the Royal Society 2022 History and Philosophy of Science Medal. See his obituary below.

2 Sarton (1956), p. 188.

3 Quoted in Kevles (1971), p. 24.

the teaching of engineering in any of the university rooms for the whole of the first year.

Three questions

This conception of the relation between science and technology prompts three questions. First, can one have technology without science? Second, rather than technology just being applied science, can it actually precede and initiate scientific investigation? Third, in cases where technology and engineering interact with scientific investigation, what actually happens? I've dealt with these questions in some detail in my *Civilization and the Culture of Science* (2020), and I'll look briefly at each of them.[4]

On the first question, it is pretty clear that much technology has been independent of science. The historian of technology, Channell, sums up the situation in these terms:

> As historians began to examine the history of technology they found little evidence for a strong dependence upon science. A detailed historical analysis of such major technological inventions as movable type printing, the mechanical clock, guns and gunpowder, metallurgy, the steam engine, textile machines, machine tools, railroad, and the automobile led to the conclusion that such inventions depended little, if at all, on scientific knowledge, skill, or craftsmanship. Historians of technology also began to challenge the common assumption that the Scientific Revolution of the sixteenth and seventeenth centuries has been primarily responsible for the Industrial Revolution of the eighteenth and nineteenth centuries. Almost every important technological development that contributed to the Industrial Revolution — such as Abraham Darby's production of iron using coke, Richard Arkwright's textile machinery and Thomas Newcomen's steam engine — owed little to any scientific theory or discovery. Even when some connection between technology and science could be identified, the connection many times turned out to be either indirect or much more complex than the applied science model indicated.[5]

Some confusion has resulted from the idea that any advances in technology must *ipso facto* be the result of science. Vannevar Bush, an engineer who directed U.S. wartime research and headed the Office of Scientific Research and Development, said that when he came to discover that his British counterparts considered that the engineer was a kind of second-class citizen compared to the scientist, he decided to designate all wartime researchers working in the Office of Scientific Research and Development as scientists. He noted that even after World War II the public was led to believe that such an achievement as the landing of the first astronauts on the moon was a great scientific achievement when in fact "it was a marvellously skilful engineering job." Such engineering jobs depend on skills that scientists do not necessarily have. The early years of aeroplane design are a good example, depending strongly on visualization and hit and miss tests. In 1917 the editor of *The Aeroplane*, Charles Grey, wrote that we should "trust the man who guesses, and guesses right," rather than the scientist, who turns "out strings of incomprehensible calculations resulting from

4 This paper draws on my *Civilization and the Culture of Science: Science and the Shaping of Modernity 1795–1935* (Oxford, 2020). The themes explored briefly here are dealt with in detail there.

5 Channell (2017) p. 10.

empirical formulæ based on debatable figures acquired from inconclusive experiments carried out by persons of doubtful reliability on instruments of problematic accuracy."

On the second question, whether technology can precede science, there are a range of views. For the philosopher Peter Janich, writing in the 1970s, "in place of the musty ideology of the researcher who unravels nature's secrets, the physicist will understand himself to have just one task: *enabling technology*," and that natural science "is to be understood as a secondary consequence of technology rather than technology as an application of natural science." These are fighting words, and we do not have to subscribe to a complete reversal of the relations of priority between science and technology to appreciate that there are cases where technology has in fact preceded science. A good example is the Giffard steam injector, devised in 1858 by Henri Giffard, an engineer whose main interest was in the construction of steam-powered dirigibles. Giffard sought a feed apparatus for his dirigible that would not be subject to friction, by contrast with force pumps, which were hindered by friction, thereby absorbing power from the engine. It worked by delivering cold water to a boiler against its own pressure, using the boiler's own exhaust steam, and by the early 1860s it had completely replaced mechanical pumps. From the point of view of physics, however, the device presented a seemingly intractable problem: the process looked, *per impossibile*, to be a case of perpetual motion, and physicists struggled to understand how the injector worked. The task was to reconcile scientific understanding with an established body of technological knowledge, but it was 50 years before a satisfactory thermodynamic explanation was offered. Gifford's steam injector was a case where the technological development preceded the scientific understanding. Nor was it so unusual. As Joel Mokyr notes, the Industrial Revolution of the first half of the nineteenth century created a chemical industry without chemistry, an iron industry without metallurgy, and power machinery without thermodynamics.[6]

Just how independent of science technology can be is highlighted by the Nobel Prize-winning physicist Robert Millikan in his 1950 autobiography, where he suggests that results in the nineteenth- and twentieth-century physical sciences derived largely from developments in engineering, providing some revealing examples:

Historically, the thesis can be maintained that more fundamental advances have been made as a by-product of instrumental (i.e. engineering) improvement than in the direct and conscious search for new laws. Witness: (1) relativity and the Michelson-Morley experiment, the Michelson interferometer came first, not the reverse; (2) the spectroscope, a new instrument which created spectroscopy; (3) the three-electrode vacuum tube, the invention of which created a dozen new sciences; (4) the cyclotron, a gadget which with Lauritsen's linear accelerator spawned nuclear physics; (5) The Wilson cloud chamber, the parent of most of our knowledge of cosmic rays; (6) the Rowland work with gratings, which suggested the Bohr atom; (7) the magnetron, the progenitor of radar; (8) the counter-tube, the most fertile of all gadgets; (9) the spectroheliograph, the creator of astrophysics; (10) the relations of Carnot's reversible engine to the whole of thermodynamics.[7]

6 Moykr (1999), p. 219–245.

7 Millikan (1950), p. 219.

The third question, that of what actually happens in cases where technology and engineering interact with scientific investigation, is especially complex. Such cases differ from one another significantly, as might be expected, but the early stages of the design of the aerofoil will at least give some flavour of the general issues. When the Wright brothers undertook the first sustained and controlled flights between 1903 and 1905, they had worked largely by trial and error. In the wake of these flights, those constructing aircraft continued in a trial-and-error fashion, building on the practical expertise of their predecessors. But at the same time there began attempts to develop a theoretical understanding of the action of the air on wings. The aim was to understand lift (the force on the wing that keeps it in the air), drag (the resistance of the air to motion), and stability (the ability to correct for pressure producing turning moments that would cause the wing to pitch). The basic mathematical resources derived from hydrodynamics, the study of bodies moving through fluids. The area was mathematically challenging, and in order to make it tractable numerous simplifying assumptions had to be made, resulting in a mathematical theory of ideal fluids. But ideal fluids are non-viscous, and so not a model for real fluids such as air. The subsequent mathematical development of a theory of viscous fluids by George Stokes provided very limited help, since they could only be solved in a few simple cases.

In the light of this, the task was to find a way of making ideal-fluid theory more realistic, and there were two basic approaches to this. The problem with perfect fluids arises from the fact that they are continuous and irrotational (they do not rotate around the body immersed in them). Two different approaches attempted to solve the problem by introducing discontinuities in the one case, and circulating vortices around the moving body in the other. The approaches were associated with very different conceptions of what the understanding of physical phenomena consisted in. The first one maintained that any account must be anchored in — and ultimately be deducible from — mathematical physics, particularly as conceived in the Cambridge Tripos tradition, the nineteenth-century home of applied mathematics/theoretical physics. The second approach, which was in the tradition of "practical mechanics," particularly as conceived in the tradition of the German technical college, the *Technische Hochschule*, rejected such foundational aspirations, and manipulated mathematical and theoretical resources in such a way as to achieve a particular engineering result.

The resistance that advocates of the first approach demonstrated to the success of the second is revealing. They worked with a model of science as something comprehensive and certain, and to a large extent, the resistance arose from the fear that this conception would be compromised by abandoning the idea that the physical nature of the world can ultimately be derived from a unified set of fundamental, mathematically-formulated physical laws. A pioneer of the engineering approach, Frederick Lanchester, started from the observation that birds' wings, which have evolved into a shape that conforms to the pattern of airflow necessary for lift, have an arched profile with a slight downward inclination at the front edge. What must happen, Lanchester argued, is that the air must be moving upward as it approaches the leading edge of the wing and downward as it leaves the trailing edge. There is an exchange of momentum: the initial upward vertical component of the motion must be reduced to zero as the air passes over the wing, and then replaced with a downward vertical component. His solution worked with the notion of an ideal fluid, but critics pointed out that in a stationary perfect-fluid setting a body in motion could not create a flow at all. But Lanchester was well aware that mathematical idealizations wouldn't work in the real world; the important thing was to learn what one could from the idealized case but not be imposed upon by it. When, in 1936, well after his circulation theory had been accepted as the correct account of lift and drag, Lanchester wrote that his work had not been taken seriously 20 years earlier because it had been judged by Cambridge-trained mathematicians.

Conclusion

Does it matter, other than in terms of professional pride, if science gets the credit for engineering and technological achievements? From the point of view of our understanding of the scientific culture of the modern world, it matters a great deal. At the end of the eighteenth century, the West's sense of its superiority had shifted from its religion, Christianity, to its science. It was the French philosopher and political theorist the Marquis de Condorcet who, in an essay published in 1795, offered the first fully fledged statement of the view that scientific progress is distinctive of Western civilization, that it was the intellectual and cultural achievements of its science that shaped modern culture. Accordingly, in the course of the nineteenth century, the notion of scientific progress was mapped on to the understanding of civilization. All cognitive values — and subsequently moral, political, and social ones — come to be modelled around scientific values.

As I argued in my *Emergence of a Scientific Culture* (2006), a crucial ingredient in the plausibility and success of this notion has been the idea that science, by contrast with religion for example, appeals solely to reason and experience, and is as a consequence untinged by historical or cultural factors, which can therefore be ignored, making science something which in essence has no context, historical or otherwise. Science is thereby protected in advance from the historicization and contextualisation that, coming to a head in the middle of the nineteenth century, eventually undermined Christianity's claims to *sui generis* legitimacy. The problem is magnified by the cultural standing that science has taken on in virtue of this image. In particular, the notion of science as something answerable to nothing but reason and experience has done much to encourage the otherwise somewhat unlikely association between scientific values, morality, and democracy.

This association began in earnest with the Darwinism debates of the late nineteenth century, and it became a dominant cultural theme in the twentieth century. In the Anglophone world, this development starts with Herbert Spencer, who, in his *Principles of Ethics* (1892) set out explicitly to derive ethical principles from scientific ones, and from the late nineteenth century onwards there have been recurrent attempts to guide morality scientifically. In 1916, for instance, Richard Gregory, the editor of *Nature*, singled out the scientific values of selflessness and love of truth to act as the basis for morality. He was followed in 1923 by the contributors to the volume *Science and Civilization*, who called for moral values based upon science to replace those based on religion, with Julian Huxley's contribution identifying the next great task of science as the creation of a new religion. By 1931, the science columnist John Langdon-Davies was taking up the defence of the moral values of science with an attack on the use by religion of emotionally loaded words to describe abstract concepts. In 1957, a member of the Mental Health Research Institute at the University of Michigan was arguing that the ethical system derived from scientific behaviour was a "superior" ethical system, and 18 years later the biologist E.O. Wilson was writing that the time might have come for "ethics to be removed temporarily from the hands of philosophers and biologicized."

The question is whether, once it is realised that the supposed practical benefits of science were in fact not due to science at all, this bloated view of science would remain so well-entrenched. There are indeed benefits from science, and values associated with science: for example, those of objectivity and impartiality are a crucial part of our culture. But the idea that all values can be anchored in those of science is both wrong-headed and dangerous. As Nietzsche put it: "As long as what is meant by culture is essentially the promotion of science, culture will pass by the great suffering of the human being with pitiless coldness, because science only sees problems of knowledge, and because within the world of the sciences suffering is really something improper and incomprehensible."

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