SCIENCE, TECHNOLOGY AND MEDICINE IN THE
UNITED KINGDOM, 1750-2000

David Edgerton and John V Pickstone

The United Kingdom of Great Britain and (Northern) Ireland has been one of the major scientific nations from the seventeenth century to the present, as is evident from any history of scientific ideas or scientific lives. That relative strength needs stressing for some modes of writing have suggested relative weakness.

For example, in a simple history of the emergence of modern scientific institutions, Britain might well be omitted, at least from the eighteenth century. In the conventional historiography of science organisations, the Royal Societies or Academies led the national scientific communities of the European enlightenment; then came the French Revolution and the creation (or re-creation) of the national museums and the professional schools for engineering and medicine; then the creation or re-creation of German state universities which pursued Wissenschaft by research. And in the later nineteenth century, Germany also pioneered the ‘science based’ industrial firm and developed elite technical high-schools and state laboratories. Research universities, technical high-schools, scientific corporations and state laboratories were taken up elsewhere, especially in the USA, and they dominated the science of the later twentieth century, not least through support by government agencies, both military and civil. Indeed, in such an account British institutions tend to appear as belatedly following foreign models. For scientific institutions, it would seem, Britain was a runner-up to Germany before WWI and to the USA thereafter. And yet in this same period, the British empire was the greatest the world had ever known, and British industry dominated world markets in ways not seen before or since.

A related tradition of historical assessment has stressed absences more than presences, bemoaning lack of funding and the underdevelopment of scientific institutions and training. From its creation in the early nineteenth century, this history of deficit was a common resort for British scientists who looked abroad and complained of lack of support at home in order, partly to increase domestic funding. In the 1820s, Charles Babbage reflected on the ‘decline of science’ compared to Continental Europe, and later

---

1 The authors would like to thank Greta Jones, Andrew Mendelsohn, Sabine Clarke, Andrew Warwick, Sam Alberti, Peter Bowler, Jeff Hughes, Jonathan Harwood, Jack Morrell, Duncan Wilson and Michael Worboys for their comments and suggestions, and Joan Mottram for her work on the drafts.
in the century scientific campaigns relied on exaggerated contrasts with other nations, especially Germany.\(^2\) This history of retardation appears to some degree in J.D. Bernal’s work of the 1930s, and very clearly in C.P. Snow’s 1950s essay on *The Two Cultures*, as well as in many later reflections by scientists.\(^3\) Many of the new academic historians of science also echoed this analysis in work from the 1950s to the 1980s.\(^4\) In the 1960s and 70s, the historiography of British scientific institutions, science funding and science policy re-enforced this picture, concentrating on the history of national bodies with science in their title, and lamenting the weakness of ‘policy’.\(^5\) Indeed, this deficit account of British science was an important element in what has come to be called the declinist historiography of late nineteenth and twentieth century Britain.\(^6\)

This is not to say that all accounts of British STM were negatively tinged. Accounts of British technology are usually positive for the nineteenth century; and for biology the attention to Darwin may be said to have balanced a significant tradition of deficit history for laboratory bio-sciences, especially before 1870.\(^7\) In histories of medical services, Britain often has appeared as exemplary, especially for early public health campaigns and for histories of the welfare state.\(^8\)

---


3 For the idea that ‘anti-histories’ of British science have been important, and are exemplified rather than exhausted by the case of C.P. Snow’s *Two Cultures* see David Edgerton, *Warfare State: Britain 1920-1970* (Cambridge: Cambridge University Press, 2005), ch. 5.


5 Thus we know a great deal about the Department of *Scientific and Industrial Research*, the British *Science Guild*, the National Union of *Scientific Workers*, the Association of *Scientific Workers*, the British Association for the Advancement of *Science*, and on central government committees with science in the title, like the Scientific Advisory Council to the War Cabinet, or Advisory Council on *Scientific Policy*. See P. J. Gummett (1980) and Peter Alter (1987) for detailed references to this literature.


The last thirty years have seen a huge increase of historical research, especially in the English-speaking world, and British STM for the period 1750-1914 has been a favoured site. But from the 1970s the favoured approaches have been social rather than political, and local rather than national. Historians of STM have anatomised locales, such as industrial cities, correspondence networks and university departments, seeking to understand the social relations of scientific experts and their interactions with wider configurations of thought. The mass of work on Darwin and evolutionism, for example, has done much to illuminate the heterogeneity of Victorian science – from its intellectual culture and religious movements, to the involvement of the British navy in surveys, to the traditions of animal breeding among farmers and pet-fanciers. Our understandings of Victorian science and medicine are now richly contextual, but less historical work has been done on the twentieth century and it is only since the late 1980s that historians have come to interrogate the inherited accounts of industrial decline and of governmental minimalism in science policy. They have sought to widen the traditional focus on universities and related bodies, by looking at medical services, firms, the military and

---


trade unions, and at government departments and committees which did not have ‘science’ in their titles. 13

In this review, we have attempted to synthesise what is now known of STM in Britain, within a framework which seeks to be inclusive, but which also draws on the principles of our own recent works. 14 In line with recent specialist historiography, we stress the varieties of knowledge and practice which are often lumped together as ‘science’. We try to distinguish ‘science’ from ‘research’ and to bear in mind that not all research is ‘successful.’ We try to include natural-historical knowledges and practices – exploration, cataloguing, classifying and displaying; and we note the significance of analytical work in STM – whether in chemistry, stratigraphy, analytical engineering, pathology, economics or phrenology, especially for the early nineteenth century. For the later nineteenth century, we look for linkages between the growth of University laboratories and the emergence of experimentalist research programmes in biological and physical sciences (including synthetic chemistry). We criticise standard declinist accounts, and try to take account of industry and the military, at least for the technoscientific enterprises of the twentieth century. We shift away from the usually implicit but very powerful association between ‘science’ and what are taken to be key elements of academic research enterprises, toward a new map of the research enterprise, which is often very different from the received picture, for example in giving a different sense of the scale at which research was carried out.15


We hope to facilitate a historiography which, without neglecting the engines of change, will better connect with economic history through its concern with the *synchronous* operations of different modes of knowledge production and utilisation. We would also wish to link more fully with political history in the widest sense – not just with the questions of science policy and university policy which have often occupied scientific academics, but with transformations of the state and of society and ideologies more generally. So if in surveying science, technology and medicine in (more or less) one country, over more or less 250 years, we explicitly return to older questions about the relations of science and the nation state, we try to do so in a way that is broader, less normative and more conscious of changing periods than was common in previous surveys. And if these ambitions have well outrun our survey, we can but hope that they will help others towards richer visions of the intersections of scientific and national histories.

**The British Enlightenment in Countryside and City**

One of the most notable features of studies of eighteenth century British science is the common focus on the provinces rather than the metropolis. London mattered, of course, but less than did Paris for France. Of all the élite pre-industrial cultures which concerned themselves with science, that of eighteenth century England may well have been not only the most provincial but the most rural. Natural history, especially botany, was a common recreation of land-owners and parsons, and of their wives and children. It was part of a culture of collections and representations that included coins and prints, books and portraits, antiques and garden plants, as well as the creations of God. And the distinctions were fluid. Landscapes were created to look like pictures, and ‘pictured’ through looking frames; prints were collected and inserted into dismembered books, or into scrap-books which could also contain pressed plants or pictures of animals. Plants could be classified, but so could portraits of English rulers, generals and bishops. Humans and their illnesses appeared in natural histories of man and in Hippocratic understanding of environments and disease. And since Britain was already a major colonial power, with great plantations in the Americas, British natural history was correspondingly global, as indeed it remained until the later twentieth century.

Interested aristocrats were mostly rooted in their country estates, where they planted gardens, collected specimens, ‘improved’ agriculture and patronised the gentry, clergy and professionals of the neighbouring county towns. They encouraged visiting lecturers and local medical charities and agricultural shows; but they spent part of the year in

---

London, where they could join special Societies for botany, say, or antiquarianism. Thus in London, as also in Edinburgh and Dublin, the knowledges of the provinces were drawn together and reinforced with the metropolitan expertise of doctors, instrument makers and lecturers. The Royal Society of London, dating from the seventeenth-century Restoration, was notably aristocratic and its Proceedings carried many reports of local phenomena. The Royal Society of Edinburgh (founded in 1783) and the Royal Irish Academy in Dublin (1785) reflected the enlightenment cultural revivals in Britain’s “internal colonies”. Scots led the renovation of London medicine though anatomy schools and museums. If Sir Joseph Banks personified the interest in exploration and natural history, the shadow of Sir Isaac Newton was the guarantee of Britain’s greatness in Natural Philosophy, and the icon of the mathematicians who taught in schools and colleges, or gave lecture demonstration in experimental philosophy.

For Enlightenment knowledge was utilitarian as well as decorative, and analytical as well as natural-historical. Indeed, in an article on the peculiarities of the English, the social historian E. P. Thompson argued that the rationalisation and empiricism usually associated with the industrial revolution was first established in the countryside of England. In those newly-enclosed landscapes, calculating tenant farmers and “improving” landlords saw that sheep might be “machines for turning grass into money.” One of the key scientific arenas of scientific London, the Royal Institution, was founded by aristocratic philanthropists in 1799 to help better the conditions of the poor by improving agriculture and the sanitation of cities. There in London, as in the new provincial centres of industry, educated gentry, clergy and doctors might discuss schemes for manufactures, or for the better running of schools or charities. This culture of ‘improvement’ was wide ranging and seamless -- well illustrated by the Lunar Society (an informal dining club in the West Midlands), by the Manchester Literary and Philosophical Society, and by the new encyclopaedias and magazines which presented ‘histories’ of industry and of society, as well as of nature.

---


Better known abroad was the Scottish Enlightenment, which ranked with that of France
and outshone the less concentrated efforts of the English. Indeed, since their own time,
the intellectual creations of the Scottish universities have been seen as major landmarks
of the European Enlightenment—in philosophy, political economy, chemistry, medicine
and engineering. From the Act of Union in 1707, when Scotland lost its own
parliament, civic leaders worried about the draining of wealth and influence from
Edinburgh to London. To stem that tide, the ‘new town’ was planned and Edinburgh
University was regenerated on the model of Leiden, to attract students from England and
the American colonies, and to educate Scottish students who might otherwise go abroad.
Lectures in the vernacular; selection from a range of courses, without taking a degree;
training in practical medicine, including chemistry; and a system of paying professors by
the number of hearers -- all made Edinburgh (and to some extent Glasgow) into a major
focus of the European market in education. Scottish doctors went to London and set up
private schools for anatomy and for medicine more generally, they founded colleges in
North America, and they formed significant minorities in the professional circles of the
northern English towns. Edinburgh was the chief university for the educated Dissenters
of England, and its teachers a major reference point for formal and informal medical and
scientific groupings in the industrialising provinces.

Politics: repression and resurgence
The history of British science, technology and medicine around 1800 was heavily shaped
by international relations; and the Revolutionary and Napoleonic Wars might be seen as
separating the characteristic cultural forms of the eighteenth-century from those of the
nineteenth. The transition was shaped in part by industrial growth, especially in the cities
of the north, and in part by the political repression which set in from 1792. So as to avoid
suppression, some of the nascent working class societies presented themselves as
engaged with science rather than politics. Middle class groupings, such as the Literary
and Philosophical Societies, found it convenient to focus on chemistry or meteorology
when their memberships were deeply divided over political and social questions.
Formerly radical schemes for philanthropic improvements, e.g. in public health, were
now reduced to emergency measures against fever and social unrest. In Edinburgh,
from the 1790s, the free-thinking enlightenment heroes came under attack from
evangelicals eager to recruit a more traditional God to the defence of public order; the
disputes over evolutionary theories were intense. The Geological Society of London,
founded in 1807, tried to avoid religious politics by focussing on the puzzles of the new

\footnote{27} N. T. Philippson and Rosalind Mitchison, ed. Scotland in the Age of Improvement: Essays in Scottish
\footnote{28} Paul Weindling, “Science and Sedition: How Effective were the Acts Licensing Lectures and Meetings,
1795-1819?”, British Journal for the History of Science, 13 (1980), 139-53.
\footnote{29} Arnold Thackray, “Natural Knowledge in Cultural Context: the Manchester Model,” American Historical
\footnote{30} John V. Pickstone, Medicine and Industrial Society. A History of Hospital Development in Manchester
stratigraphy. Humphry Davy, a protégé of radical medical circles in Bristol, moved to the Royal Institution in London and became more conservative. He made spectacular use of one of first public laboratories, becoming the main British actor in European debates about electricity and chemistry. He was also the patron of Michael Faraday, the humble-born philosopher of electricity, who proved exemplary both for self-help and for experimental physics.

Because intellectual commerce with France was disrupted until after Waterloo, the Revolutionary changes in professional education and museums were little felt in Britain until the 1820s, when, for example, medical students began to visit Paris to complete their training. In mathematics, the 1820s saw the ‘analytical revolution’ which brought French mathematical and pedagogical methods to Britain, and especially to the great mathematical university of Cambridge. After the political crisis of Peterloo (Manchester, 1819) the provincial middle-classes found their voice again, in part to speak of reforms that would head-off the growing threat of working-class disorder. And when the British ‘ancien régime’ ended, symbolically, with the Reform Act of 1832, the new regime in London, and especially in the provinces, gave larger roles to merchants, industrialists and professionals. Many such professionals and activists were keen cultivators of science. Indeed, while certain kinds of natural theology and natural philosophy could serve as a shield for conservatives, the ‘science’ which spanned the new analytical disciplines was becoming a weapon for reformers and radicals alike.

Medical students and some of their teachers had a reputation for political radicalism, and their evolutionary theories encouraged politicised artisans to develop anti-clerical accounts of man. In the more radical of the Mechanics’ Institutes from the 1820s, and in the socialist ‘Halls of Science’ around 1840, evolutionary speculation mixed with versions of political economy that stressed property in skills as much as in capital, and with phrenological teachings that promised deep knowledge of character. Though the working classes were sometimes allowed into middle-class museums, many workers with a taste for collecting and naming plants exercised their skills in public-houses, to the

---


distress of their would-be patrons who liked to draw a line between drink and self-improvement.\textsuperscript{36}

These plebian and radical contexts and doctrines have proved attractive to historians for political reasons as well as for the connection with Darwinism; but one should not underestimate the opposition – the mobilisation of science by Whigs and liberals, and indeed by conservatives. Most Mechanics’ Institutes were in fact run by middle-class paternalists, and their clients were often shop-keepers and clerks seeking advancement. To approximate the laws of liberal political economy to those of Newton lent the former a useful inscrutability; and phrenology, for many artisans as for its middle-class adherents, served to reinforce individualism.\textsuperscript{37} And though comparative anatomy could be subversive of man’s special status, and the importation of continental medical sciences provided a niche for young doctors, the medical profession remained dominated by hospital consultants not noted for their intellectual or social concerns. Public health and ‘state-medicine’ were indeed radical causes in the 1830s, but few doctors showed much interest until the 1850s.\textsuperscript{38} Reform in medicine rarely went beyond the demands of a new technical intelligentsia for powers within professional organisations to match those which the middle classes more generally were gaining in local and parliamentary politics.\textsuperscript{39} Whig intellectuals held to middle roads, and from the 1820s they had a London base in what became University College (conservatives founded King’s College to bolster Anglican claims). They used their political connections to campaign for some government funding for science, and succeeded in establishing the Geological Survey (1835).\textsuperscript{40}

The Royal Society of London was reformed in 1847 to make it a professionally oriented learned society, and new national societies were formed, eg the Astronomical Society of London, (1820), and the Chemical Society (1841). Engineers created the Institution of Civil Engineers (1818), which covered included parliamentary work for transport schemes, and the Institution of Mechanical Engineers (1847) which was more provincial and industrial in orientation.\textsuperscript{41} The British Museum was developed as a base for taxonomy and comparative anatomy, a new Museum of Practical Geology was linked with the Geological Survey, and pathological museums became essential to medical schools -- whether private or in the teaching hospitals. Commercial and educational

museums were set up, often in the hope of popularising technology and encouraging invention.\textsuperscript{42}

Across the United Kingdom, and not least in great new industrial cities, local societies for science flourished. Manchester, for example, alongside its Literary and Philosophical Society (1781), sprouted societies (and museums) for natural history, geology, technology and phrenology. And the provincial enthusiasts so gathered were recruited by metropolitan ‘gentlemen of science’ into the new British Association for the Advancement of Science, a pressure group consolidated though annual meetings in different cities.\textsuperscript{43} The same pattern of organisation, characteristic of liberal reform, was followed by what became the British Medical Association.\textsuperscript{44} The leaders of the BAAS mostly held paid posts in the universities; the ‘British Ass’ linked them with the occasional lecturers, periodical writers and with the enthusiasts for natural history, astronomy, microscopy or photography who generally met in local scientific societies, and who helped constitute the common context of middle-class thought, recently anatomised in James Secord’s study of responses to evolutionary doctrines.\textsuperscript{45}

**Industry and analysis**

Accounts of the industrial revolution written in the decades after the Second World War tended to focus on the possible inputs of science to technology, and on the origins of the technical universities and technical institutions.\textsuperscript{46} Later historians have stressed the many different roles of technical knowledges, latent as well as patent. They have looked less to industry than to civil engineering, government regulation, military and naval forces, medical professionalisation and the social roles of the sciences for middle or working-class groupings.\textsuperscript{47} It has been hard to find science ‘applied’ in industry, except in the chemical trades, but one might argue more widely -- for common attitudes demonstrated in both knowledge-seeking and money-making. For example, the inventions of textile machines by Lancashire artisans might be linked with their contemporary fondness for mathematics and botany as the (short-lived) prosperity of domestic hand-loom weavers


\textsuperscript{46} A. E. Musson and E. Robinson, *Science and Technology in the Industrial Revolution* (Manchester: Manchester University Press, 1969); D.S.L. Cardwell, ed., *Artisan to Graduate; Essays to Commemorate the Foundation in 1824 of the Manchester Mechanics’ Institution, now in 1974 the University of Manchester Institute of Science and Technology* (Manchester: Manchester University Press, 1974).

encouraged a culture of self instruction and an appreciation of ‘novelties.’ Or, at the level of the urban professionals by the 1820s, we can see chemists, engineers, industrialists and doctors trying to ‘take apart’ chemical matter, mechanical motions, industrial processes or industrial society, so as to better understand the structures and dynamics across the range of the new sciences. Their analytical methodologies and ideologies helped link the rationalisation of industrial production with the political economy of Ricardo and with new analyses of the natural world then being produced by emergent ‘scientists’.  

Indeed, as one of us has argued at length, the first half of the century, in Britain as in France, was notable for analytical sciences and practices based on ‘elements’ that were specific to each of these newly constituted disciplines. Lavoisier’s new system of chemical elements was the paradigm, but geology, botany, zoology, general anatomy and engineering all had their elements (eg strata, tissues, and elementary machines) from which bodies of various kinds were seen as compounded. In the spaces between natural philosophy, chemistry and engineering, new physical disciplines were created around the elements of heat, light and the various kinds of electricity. As John Herschel noted in Britain’s most popular guide to scientific method: ‘In pursuing the analysis of any phenomenon, the moment we find ourselves stopped by one of which we perceive no further analysis…….the study of that phenomenon and of its laws becomes a separate branch of science’. It is no accident that in Britain as in France, there was much contemporary interest in the classification of the sciences, or that traditionalist natural philosophers such as William Whewell regarded the new disciplines as too unstable to serve as the basis for a scientific education, which should continue to be grounded in mathematical natural philosophy.

For all these new subjects, the professional institutions of France were major crucibles, but in those fields close to agriculture and industry, eg stratigraphy, chemistry, work/energy and political economy, British analysts were much more than copyists. Whig reformers (and some Tories and Radicals) ranged across these nascent disciplines and built them into political arguments. Charles Babbage, who had helped introduce French mathematics to Cambridge, also argued for the division and mechanisation of mathematical labour; he philosophised about industrial work as he lamented the lack of support for science in Britain. The physician James Kay (-Shuttleworth) analysed the social body of Manchester, guided by the physiology he had learned at Edinburgh and the political economy of Ricardo; he moved to become a Poor Law Commissioner under

---

48 Pickstone, Ways of Knowing, 83-102. The links between political economy and science have been a theme of the literature on for example, Babbage and Kelvin. See also Margaret Schabas, A World Ruled by Number: William Stanley Jevons and the Rise of Mathematical Economics (Princeton NJ: Princeton University Press, 1990).

49 John Herschel, Preliminary Discourse on the Study of Natural Philosophy (London: Longman, 1830).


Edwin Chadwick, and then the first central administrator of English education.\(^{52}\) His Manchester contemporary, the devotee James Prescott Joule, applied himself to natural philosophy rather than social analysis. A student of John Dalton and a son of a brewing family, Joule was sceptical of the 1830s enthusiasm for electrical machines, so he measured their efficiency, as practical engineers had learnt to assess that of steam engines. From which results he went on to conceptualise and measure the mechanical equivalent of heat, and so, via William Thomson’s Cambridge mathematics and Glasgow engineering, laid one route to the principles of thermodynamics.\(^{53}\)

We know less about engineers, which is a pity, not just because of their economic and social importance, but because of their intellectual creativity. In the engineering of the industrial revolution, one sees the interactions of analysis (formal or informal) and creativity, by which many mechanical devices could be combined in imitation and magnification of craft operations. Richard Roberts’ invention of the spinning mule, in part to break a strike, was remarkable for the complex interplays by which he solved a problem that had defeated many others. James Nasmyth’s steam hammer could far exceed the power of any previous hammer, but it was also displayed gently breaking the top of an egg. Both Roberts and Nasmyth, like Joseph Whitworth and many other machine creators, trained in the London workshop of Henry Maudsley – a practical school of astonishing fertility, stressing measurement and standardisation. One major preoccupation of more formal engineering schools on the continent was the systematic ‘reverse engineering’ of British machines.\(^{54}\)

**Education outside the state**

That the development of the sciences in the nineteenth-century depended heavily on the growth of educational institutions is a truism, and yet its application to Britain has been less evident than for France or Germany, partly because of the contemporary and historiographical stress on *deficit*, and partly because British higher education was so varied in its constituents, and so little controlled by the central State, that the overall shape of the British developments has been harder to see. Educational institutions were mostly denominational; indeed, to be non-denominational much before mid-century was in effect a sectarian position. The United Kingdom was a Protestant nation – Catholics were ‘emancipated’ only in 1829; and its established Protestant churches vied with


The key Anglican institutions were Oxford, Cambridge and Trinity College, Dublin.\footnote{The History of the University of Oxford (Oxford: Oxford University Press, 1984-), vol. 8: The Twentieth Century (1994), ed. B. Harrison; Peter Searby, *A History of the University of Cambridge*, vol. 3: 1750-1870 (Cambridge: Cambridge University Press, 1997); The History of the University of Oxford, vol. 6: The Nineteenth Century Part I (1997), vol. 7: The Nineteenth Century Part II (2000), ed. M. G. Brock and M. C. Curthoys.} Cambridge and Oxford – which excluded even Protestant dissenters -- were much larger, relatively, than they are today; in mid-century some 100 students graduated in mathematics from Cambridge each year. Indeed, Cambridge in particular had been reformed in the late 18\textsuperscript{th} century with the introduction of written exams, and later the development of very intensive and large-scale pedagogical regimes based on mathematics. Though most of these graduates went on to non-mathematical careers, Kelvin, Maxwell, Stokes and many other luminaries of science were numbered amongst the products. Indeed Cambridge mathematicians represent one of the main British contributions to 19\textsuperscript{th} century science.\footnote{Andrew Warwick, *Masters of Theory: A Pedagogical History of Mathematical Physics at Cambridge, 1760-1930* (Chicago: Chicago University Press, 2003).} Oxford, though dominated by classics, had professors in several sciences -- some of them active, not least as natural theologians.

The Scottish Universities and the emergent London University were open to all faiths and more open to the new sciences. So too were the Queen’s Colleges of the 1840s in Cork, Galway and Belfast, but the Irish catholic hierarchy banned their flocks from them, leaving Irish science almost wholly Protestant. Most of the great Irish-born scientists – including Kelvin, Stokes, Tyndall, Larmor, Fitzgerald, Stoney and Joly, were Protestants\footnote{Andrew Warwick, “The Sturdy Protestants of Science: Larmor, Trouton and the Motion of the Earth Through the Ether,” in Scientific Practice: Theories and Stories of Doing Physics (Chicago: University of Chicago Press, 1995), ed. J. Z. Buchwald, for the Irish dimensions of electromagnetism (including Stoney and Fitzgerald).} – though under Cardinal Newman, a non-endowed Catholic university college emerged in mid-century (later UCD). Dublin was then a notable centre for clinical training, especially in obstetrics, and there were many Catholic medics of distinction.\footnote{Greta Jones, “Scientists against Home Rule,” in Defenders of the Union: A Survey of British and Irish Unionism (London: Routledge, 2001), ed. D. George Boyce and Alan O’ Day, 188-208.}

In England, the education of family doctors had been based largely on apprenticeships, but between 1815 and 1858 reformist doctors and their parliamentary allies established formal lecture courses and dissections as the necessary base of all medical education.
The old medical corporations adapted to survive; they loosened their ties with Oxbridge and the Church, and made good profits as examining bodies. The growth of formal medical education, in the hospitals schools of London as in the proprietary medical colleges of the provinces, gave partial livings to teachers of chemistry, natural philosophy and botany, as well as of the new medical sciences. And from the 1840s, in London, medical students could also attend a new kind of college for scientific professionals; at the Royal College of Chemistry, A.W. von Hofmann brought to Britain the practical education in chemistry (and pharmacy) pioneered by Justus Liebig at the University of Giessen. Would-be professional chemists could now study at home in Britain; but the College failed as a private venture, becoming part of the complex of hopefully useful scientific institutions supported from mid-century by the state and mostly collected into South Kensington -- which, for all its debts to (the German) Prince Albert, was in many ways the French aspect of British science -- a set of national educational museums and technical schools.

From mid-century, pressures mounted to reform the ancient universities. Reformers inside the Universities hoped to benefit their disciplines by professionalising academic life and promoting research, as in Germany. Many of the external reformers were provincial Dissenters, keen to open up the ancient universities for the next generation. Similar campaigns were mounted for the reform of the élite boarding schools -- for the better moral-discipline of young English gentlemen and to maintain the intellectual legitimations of that social class against the claims to new knowledge evident in the northern cities and the technical professions. In this context it mattered that some gentlemen were world famous for devotion to science. As Lyell, Darwin and Joule resoundingly showed, scientific research work of major importance was done by men of independent means or commercial employment.

In the northern cities, the higher education institutes most characteristic of the early century had been denominational colleges for clergy of various Dissenting kinds. From mid-century, secular colleges were founded, some of them (for example, in Manchester, and later Liverpool) with traditional curricula that contained arts subjects as well as sciences. Some, like Sheffield and Birmingham, concentrated on the sciences that were to benefit local industries. Some came close to failure, but by about 1870 they were thriving. Leading local industrialists were supporting academic entrepreneurs in developing science laboratories, especially for chemistry; and proprietary medical schools were amalgamating with the colleges, in part to secure the pre-clinical science teaching that medical educationists had managed to make compulsory under the 1858

---

Generally, the colleges benefited from the growth of a ‘diploma culture’ -- the University of London acting as a national examination board.63

In London by the later nineteenth century, interconnecting networks of educationalists, consultants, businessmen and researchers were evident.64 From about mid-century, there developed a whole new layer of experts working for businesses and especially for the state. The latter category included various kinds of public health doctor, chemists involved in the Alkali Inspectorate, inspectors of education (for example Matthew Arnold) or of Fisheries (a post T H Huxley once held). Inspectors, as MacDonagh showed, tended to find new problems and breed further inspectors;65 and when we look to T.H. Huxley and his co-conspirators in the X-Club, we see how an emergent scientific community lobbied for influence, power and the provision of new colleges that could accommodate their protégés.66 Their message still has radical resonance – science, as a method, embodied the spirit of practical criticism, it questioned all tradition, including religion; it was the way of the future.67

We should not assume, however, that these campaigning professionals generally worked in research laboratories, as these would be understood by 1900. Some had laboratories for creating philosophical novelties, notably Faraday at the Royal Institution, but most professional scientists around mid century curated museums, or they analysed specimens for knowledge, diagnoses, or profit; they lectured to large classes and performed demonstrations – but they were not masters of experimental physics or physiology, nor did they develop research schools. Even T.H. Huxley, the Moses of experimental biology in Britain, did his own taxonomic and analytical biology in museums or in the field; and though many younger scientists owed their positions to him, he had no direct research descendents such as they would later boast.

Indeed, the growth of higher education in mid-century boosted the museum sciences we have discussed for the early century. Thus the first major scientific institution in Oxford was the University Museum (of Natural History, with chemistry added on) promoted by Ruskin and opened in 1861. In London, the Royal School of Mines was associated with the Museum of Practical Geology; and when T.H. Huxley built the Normal School of Science in South Kensington to educate science teachers, it too contained a museum. In the 1870s the Natural History collections of the British Museum were moved to a splendid new Gothic cathedral of science in South Kensington; and from about the same

65 Oliver MacDonagh, Early Victorian Government (London: Weidenfeld and Nicolson, 1977)
date, throughout the country, municipal governments were developing public museums, often incorporating collections which had been assembled by local natural history societies and were used by the new civic colleges.68

Yet even as museums gained huge public audiences, they began to be marginalised in the academies, where from the 1860s professors of physical sciences concentrated on developing laboratories. These were first intended for the instruction of students, but some later housed organised research by advanced students and staff. Chemistry had led the way with the teaching laboratories of Thomas Thomson in Glasgow, and Hofmann in London. And when Owens College, Manchester, raised money for extension and moved to its present site in the early 1870s, about half the space in the new building was devoted to Henry Roscoe’s chemical institute – as large as anything in Germany and closely linked with local industry via consultancies and the provision of graduates.69 Physics followed. Glasgow boasted a physics laboratory created by William Thomson to give practical training to large numbers of students, while also serving his industrial connections, especially for telegraphy, which demanded laboratory testing and skilled technicians.70 Indeed historians have fruitfully explored the connections of electrical telegraphy – particularly submarine telegraphy – with the emergent British physics and electro-magnetic theory.71

The Cambridge pattern was interestingly different from that of London and the industrial provinces, with less stress on chemistry. Two of the most fertile institutions in modern British science—the Cavendish laboratory for physics and the Cambridge physiological laboratory -- were founded around 1870. The former was funded by the Duke of Devonshire, who was also a mathematician, an industrialist and a statesman for science, who in the early 1870s chaired a massive enquiry into the state of British science. Its many recommendations largely went unfunded, but the institution he gave to Cambridge, sometimes then called a museum for physical science, proved crucial in diverting some of Cambridge’s mathematical prowess towards experimentalism. The Cavendish failed to take off as a teaching lab until the mid eighties, but became a centre for analytical work on electrical standards, closely related to the telegraph industry. From the 1890s it was a major experimentalist laboratory with a programme of research around cathode ray tubes, led by J.J. Thomson.72

Physiology benefited from the scientisation of the national medical curriculum, as previously mentioned. In several universities, physiology laboratories were introduced to link medicine with the science faculty, and to teach medical students the virtues of scientific analysis and experimentation. But only in Cambridge and University College London were physiology research schools successfully established, partly because their medical scientists were not overshadowed by clinicians. Cambridge physiology, like physics, benefited from the recent incorporation of Dissenters among staff and students, and from the endowments of certain colleges, notably Trinity. By the end of the century, Cambridge could entwine social privilege and intellectual excellence for physics and physiology as well as for mathematics. From 1895, when Cambridge laboratories were opened to graduates from elsewhere, they proved attractive to colonial scholarship boys as well as to rich Britons.  

Overall, the patterns of disciplinary development in Britain, though somewhat later, were not so different from Germany, which remained the usual exemplar. By about 1890, ‘endowment of research’ featured in funding campaigns for Universities, and schools of advanced students working under key researchers were the norm in most disciplines by about 1900. But, like the endowment of universities for teaching, and quite unlike the German model, the endowment of research laboratories in British Universities was largely a matter of private philanthropy. So too was the provision of new teaching hospitals which sometimes accompanied the new Universities, and which emphasised research and education as well as care. Medical research, especially around bacteriology, became a favoured object for philanthropy, in hospitals, universities and a few independent institutions. As in the USA from the same period, crucial large donations often came from the fortunes of industrialist and merchants -- for example, the legacy of Joseph Whitworth, the Manchester engineer, which helped provide a new technical college and a teaching hospital, as well as an art gallery and scholarships for would-be engineers.

---

On physiology, see Geison, Michael Foster; on Cambridge medicine more generally, see Mark Weatherall, Gentlemen, Scientists, and Doctors: Medicine at Cambridge, 1800-1940 (Rochester, NY: Boydell Press in association with Cambridge University Library, 2001).


See for example Michael Worboys, Spreading Germs. Disease theories and Medial Practice in Britain, 1856-1900 (Cambridge; Cambridge University Press, 2000).

Education, Industry and Empire (1890-1914)
Towards the end of the nineteenth century, the lobby for science took a more aggressive form, calling now for state endowments for research and the reform of the state along more technocratic lines. Britain was seen as falling behind Germany, and government and industry seemed backward in support of scientific and technical education as well as research. Campaigners tended to ignore the existing, very varied provision for education, and its rapid development. Technical colleges then owned by the local governments of major industrial cities, educated industrial workers in the analytical disciplines, but by 1900 they were also venturing into experimental research, rivalling the University colleges, which were also expanding. A crude estimate would suggest that the number of annual graduates in science and engineering increased fourfold in 20 years. The general increase in the quality of scientific and technical education was evidenced by the disappearance from British firms of foreign and foreign-trained scientists and engineers. Future academics, too, were less likely to go abroad for post-graduate education, once they could benefit from self-sustaining research schools in British universities. We have already noted two Cambridge cases; in London, University College had research schools around William Ramsay in chemistry and Karl Pearson in statistics, to take but two. In Manchester, by the Edwardian period, there were strong research schools -- in chemistry under W.H. Perkin, and in physics under Schuster and then Rutherford.

That the state had become concerned with technical education and research owed much to industrial and imperial imperatives; Britain had come to fear competition, especially from Germany and the USA in this age of the ‘New Imperialism’. But the national government was also worried by the growth of the political power of labour — and welfare services, including support for medicine, were promoted as an alternative to socialism. The models for state welfare, as for state intervention more generally, were often German, as in the case of the National Physical Laboratory, but in some cases there was an explicit rejection of the German model of provision, and comparisons with continental countries need to be carefully made. For example, whilst on the continent most universities, higher technical school and medical school were wholly owned by the state (in Germany not the Reich but the state governments), this was rarely the case in Britain, where the Universities were mostly charitable corporations. The exceptions were the new technical colleges owned by the major cities and towns, plus the rather special case of the Royal College of Science, which incorporated the Royal School of Mines, together with the private City and Guilds College, and was later transferred (1907) from the ownership of the Board of Education to the new Imperial College of Science and

---

Technology. Ireland too had a state-run Royal College of Science in Dublin, in a building later taken over by the government of the Free State.  

In another important respect the German model was not followed. Britain, with some partial exceptions, integrated ‘academic’ engineering into universities, rejecting the continental model of separate engineering schools. And from about 1870, British medical schools, which had tended to be separate from universities except in Scotland, became increasingly integrated into universities, first in the provinces and later in London. Many of the rapidly growing ‘civic’ universities were given independent charters in this period, with the right to examine their own students. Their income came from central and local government, from private donations and endowments, and from student fees (some covered by local government scholarships).

Mixed finance was evident also for purely research institutes, even new ones. In agriculture, state-funding for research was seen as an alternative to ‘tariff reform’-- a means of boosting British interests without sacrificing the principle of free trade. Agricultural science was developed together with rural roads, through the agency of the Development Commission created in 1909; and some of the money went to the private Rothamsted experimental station. The National Physical Laboratory (1900) was financed not just by government but also by fees and private donations.

For medical science, Britain had struggled to found a research institute (eventually the Lister Institute) comparable to the Pasteur Institute in Paris, but as concern with infant mortality mounted at the start of the new century, medical research appeared as one means of building a larger, healthier population, and hence a more efficient state. A Medical Research Committee, formed under the 1911 National Insurance Act, was expected to focus on tuberculosis but was soon dominated by Cambridge physiologists who helped establish a presence within government for the elites of British science and education. But here again, mixed finance was crucial. Cancer research was supported by two charities established for that purpose (in 1899 and then in 1923). Through Henry Dale, the Cambridge bio-medical elite was linked to the Wellcome Physiological Laboratories, supported by Wellcome’s pharmaceutical company. The key British figure in bacteriology, Sir Almroth Wright, funded his extensive research programme at the

82 From 1900 it came under the supervision of the new Irish Department of Agriculture and Technical Instruction. It became part of UCD in the 1920s.
86 Eileen Magnello, A Century of Measurement: An Illustrated History of the National Physical Laboratory (Bath: Canopus, 2000).
Microbiology, parasitology, entomology and mycology were central to that other great motor of science c.1900 – the ‘constructive imperialism’ which was meant to extend British political and economic power in Africa and Asia (and parts of South America). In Liverpool, ‘tropical medicine’ and associate disciplines were funded by local shipowners; in London, the School of Tropical Medicine was government-led.\textsuperscript{89} We know less about the effects of constructive imperialism on physical sciences and engineering.\textsuperscript{90} But one should not forget that the era of the new imperialism was also a period of expanding world trade, and many of the most important destinations for British investment, technical personnel and equipment were other rich nations, including the emerging white dominions, the informal empire in Latin America, and of course the United States. Britain was the greatest exporter and importer in the world.

The decades around 1900 saw a global arms race, and in the armed services too one sees a concern with research and experimentation, and the entry of university-trained civilian researchers into military and naval laboratories, including the new Research Department at the Woolwich Arsenal (1902) and the Royal Aircraft Factory (1909). The dreadnought and super-dreadnought battleships, combining heavy guns and armour plate with analogue computers, elaborate range-finders, radio, oil-burning boilers, steam turbines and much else, were the creation of the Royal Navy and private arms industry, which was clearly investing in research before the Great War.\textsuperscript{91} In industry more generally, there were many examples of laboratories being established for the development of new products and process. Sheffield steel provides a clear example of the development of research before 1914 in a field usually condemned for technical backwardness. British industrialists organised research in many fields, from heavy chemicals to dyestuffs, from pharmaceuticals to explosives, often drawing on German models established twenty years ago.


earlier. But note that even in laboratories designated for research, most workers practised the analytical techniques of chemistry, electro-technics, pathology or bacteriology; they produced diagnoses and improved quality control. The use of laboratories for novel syntheses and other kinds of product development was rare before the turn of the century.

The backwardness of British businesses in research in this period, and indeed later, has been exaggerated in a historiography overly influenced by contemporary complaints and crude assumptions about the link between research and economic development. The much-analysed loss of synthetic dyes/drugs production to Germany should be seen in context – Germany, for all its graduate chemists, then had little else in the way of chemical industry, and no other country (except Switzerland) developed major research-led firms in this field before the Great War. Yet it is necessary to recognise the significance, in Britain as elsewhere, of the entry of foreign firms, most notably in the newest industries. Already before the Great War, General Electric, Westinghouse, Ford Motor Company and Eastman Kodak had large British operations, as did some firms of German origin, including Siemens. For a country used to exporting technologies, this counterflow was unsettling.

In political discussions, technical experts were heard at the highest levels, and some political-intellectual movements, for example the Fabian Society, embraced a notably scientistic form of politics. Party leaders with an interest in science included R.B. Haldane, the noted liberal lawyer (and brother of the physiologist J.S. Haldane), who was a leading figure in university reform, army reform, and the law; and on the conservative side, Arthur Balfour, who was closely connected to Cambridge science. There was, moreover, a strongly nationalistic, technocratic and anti-democratic scientific lobby in the Edwardian years: national efficiency was the watchword for many reform campaigns, including the eugenics movement which sought to limit the reproduction of the lowest classes, attributing their plight to biological, transmissible inferiority. Unlike the USA, British eugenics was mostly about class rather than race – though Jewish immigration was an issue. Many public health doctors regarded talk of national degeneration as


mythical, and British eugenicists preferred to segregate the mentally subnormal rather than sterilise them; but from c 1900 through to the 1930s, selective breeding was attractive politics on the left as well as the right.\footnote{96}

The Great War and After

In the standard story, the Great War revealed to the British state the consequences of its previous neglect of science. The weakness of Britain’s science-based industry was singled out by scientists at the time, and by historians since, as the cause of relative German success.\footnote{97} Worse still, the government was prepared to send scientists to the front to die as common soldiers -- the case of the physicist Moseley became iconic.\footnote{98} The state, in this account, belatedly responded by creating a Department of Scientific and Industrial Research which then continued into the peace.\footnote{99} But that story underestimated the centrality of the military departments and the Ministry of Munitions.\footnote{100}

Further, much of the scientific mobilisation needs to be understood as a response to characteristics of the war which could hardly have been anticipated. It was a long war, in which Britain was forced to send a mass army to the Western Front. In medicine, the sheer scale of Western-Front warfare hastened innovations such as the organisation of orthopaedics as a surgical specialism, a process aided by the American surgeons. But of course, much of the new organisation ended with the war and the return of facilities to their previous peace-time uses; professional advantage had to be fought for again in new ways, though the frame of possibilities was undoubtedly changed.\footnote{101} the potential for

\footnote{96} For an account of more technical genetics, see Oren Solomon Harman, The Man who Invented the Chromosome: a Life of Cyril Darlington (Harvard University Prss, 2004)
specialisation was clearer and medical research had proved its utility for preventive medicine and the treatment of wounds. The MRC benefited greatly, and doctors’ experience of mass organisation informed schemes for the rationalisation of peace-time medical services, which in turn shaped the national planning during WWII.\(^{102}\)

To those involved, it seemed clear that war had been good for research. New linkages had been forged, and through a great variety of state institutions -- whether old, reformed or new -- more money became available. And despite the economic problems of the interwar years, the research enterprise developed strongly. Growth was slower than in the Edwardian years, and there were few institutional innovations, yet the change of scale of activity was very significant. The British armed services were pioneers in ‘big science’; they created large staffs of civilian researchers collaborating (and sometimes competing) with the technical arms of the forces. Directors of Scientific Research were appointed for the Navy (1920) and the Air Force (1925), though not until 1938 for the Army. Some of the defence laboratories were much bigger than academic laboratories, eg the Research Department at Woolwich, the Royal Aircraft Establishment at Farnborough, and the chemical warfare establishment at Porton Down.\(^{103}\) And the continued expansion of the empire, together with the greater imperial orientation of trade, supported the development of research in many other fields, from food preservation to locust control, funded by a variety of institutions including the Empire Marketing Board.\(^{104}\) New means of communication also benefited: imperialism, radio and aviation proved highly synergistic.\(^{105}\)

Britain was no longer so committed to free trade, and the once-dreaded Protection became a key feature of economic life. Like many new industries of the 1920s, dyestuffs

---


---
grew up behind selective import controls.106 Imperial Chemical Industries (ICI), formed in 1926 by the merger of three firms based mainly in the north of England and Scotland, dominated heavy chemicals, explosives and dyestuffs, and was the largest research-performing firm in the country. Its big projects were in synthetic ammonia (to provide fertilisers for the empire) and coal hydrogenation (to use surplus coal, and produce a domestic source of petrol); it recruited its main chemists from Oxford and its engineers from Cambridge. The large electrical concerns, such as Metro-Vickers, GEC, and British Thomson Houston, were also notable for their R &D, but almost all large manufacturing concerns undertook some research by the later 1930s, mostly in specially assigned laboratories. Characterisations of British industrial research effort in this period as deficient, over-dependent on DSIR-funded ‘research associations’ and failing to follow the German and especially US model of large corporate research laboratories, seem to derive from underestimates of the scale of industrial research and its significance for British firms.107

Much of the better known government-funded research was effectively controlled by civilian scientists who sat on the Medical Research Council, the Department of Scientific and Industrial Research, and the Development Commission, founded before or during the war.108 Importantly, and controversially, such bodies were attached to the centre of government, rather than to ministries with specific functions; under the ‘Haldane principle’ they enjoyed an autonomy denied to research divisions that reported directly to the military Ministries or the new Ministry of Health.109 All the research councils placed a great emphasis on what they called ‘fundamental’ science. Some of the research they funded was carried out in universities, some in semi-private institutions like the Rothamsted agricultural laboratories or the Lister (medical) Institute, and some in laboratories owned by the funding agencies themselves, the largest of which was the National Physical Laboratory (now firmly within government, under the DSIR).110 Both contemporaries and historians have asked whether there was much connection between this ‘fundamental’ state-science and the practices of the hospital, the farm and the

109 It should not be thought, as is sometimes evidently still the case, that it applied to all, or the bulk, of government research. It applied to a small fraction only.
factory. Many leading clinicians were suspicious of the MRC and resentful of its condescension towards the ‘empiricism’ of practice; they believed research ought to be led by clinical problems, whereas the MRC expected medical improvement to flow from laboratory experimentation and analysis as exemplified by the (Canadian) discovery of insulin. To extend their research ethos into medical practice, the MRC pushed for research clinicians to be appointed to University hospitals, and they used American precedents and funds; but since private consultant practice was much more remunerative than professorial salaries, clinical research remained marginal in Britain until the NHS after WWII. For example, though the MRC could point to successes in the small medical school at Sheffield, in the larger provincial schools such as Manchester, advocates of salaried clinical research were repeatedly frustrated by financial stringency and by the reluctance of their protégés to reduce their private practices. Much of the research in medical schools was funded though philanthropic foundations based on new industrial money. The Rockefeller Foundation (based in the USA) promoted public health programmes, clinical research, and the application of physics and chemistry to the understanding of living materials. William Morris, the Oxford car manufacturer who set up the Nuffield Trust, was especially generous to his local University. It seems that in the late 1930s the MRC and charities each contributed about £200,000 per annum to medical research.

From the 1920s, the elite Universities also received substantial funding from central government, including the University Grants Committee and the ‘research councils’, and with increased funding came a much larger scale of university research. By the 1930s, as J.D. Bernal noted, British university laboratories housed around 1500 research students and some 100 research fellows. These, however, were distributed very unevenly both between subjects and between sites: research was largely in ‘science’ rather than ‘technology’. Chemistry, physics and mathematics were favoured, and there were great differences between universities. The strength of Cambridge was quantitative as well as qualitative: it became the centre of pure science, famous for nuclear physics in the Cavendish laboratory, and for physiology and its new daughter -- biochemistry. In chemistry the key centres now included Oxford, as well as the large civic universities and London; most of the departments heads had trained outside Oxbridge, and often also in Germany. By the mid thirties, University College London’s chemistry laboratory had

---

111 Paolo Palladino, "Between Craft and Science"; Keith Vernon, "Science for the Farmer?"
114 Bernal, Social Function, 49-50.
116 Bernal, Social Function, 37.
two professors, two readers, two senior lecturers, and seven lecturers; it turned out more than ten PhDs every year.\textsuperscript{117}

One important consequence of industrial shifts and the greater involvement of the central state in teaching and research was a geographical redistribution of research and innovation. By comparison with the nineteenth century, Scotland now figured less strongly as a site for research and the development of new industries. The great civic universities of the north of England also lost some proportionate strength with the decline of their older local trades and the spread of new industries in the midlands and the south. Industrial combines with headquarters in London tended to build their laboratories in the south east, which is where most of the government’s military and civil laboratories were located, including those for medicine and agriculture. As business came to be recognised as a graduate career, so major companies became more involved with socially elite universities, and the late Victorian linkage of useful-science with the provinces weakened. All these tendencies benefited Oxford and Cambridge, where academic modernisers were keen to recruit research school leaders, often from the provinces.

The culture of independent Ireland was notably less scientific than that of Scotland or indeed Wales, despite the efforts of the mathematician President Eamonn De Valera and his Dublin Institute of Advanced Studies. After 1922, the new Irish Free state dropped out of the British funding system but failed to establish a strong research base of its own. Its favoured Universities were dominated by nationalists and catholics with little sympathy for the largely protestant ‘modernisers’, or for the persistently protestant tradition of Trinity College, Dublin. Irish nationalism chose to pursue policies which directly and indirectly distanced Irish nationalism from science,\textsuperscript{118} and scientific Irishmen still tended to seek careers in Britain – J.D. Bernal and E.T. Walton being important cases.\textsuperscript{119}

In the later 19\textsuperscript{th} century, most science graduates went into teaching; only chemistry had afforded substantial professional employment for its practitioners. By the interwar period, physics and biomedical disciplines were also recognised as scientific professions, providing manpower not just for research, but for all the monitoring that was becoming integral to medicine and agriculture as well as new industry. The vast majority of industrial scientists were occupied with analytical work and quality control; and the research councils had large programmes on standardisation – for example the MRCs concern with the standardisation of ‘biological’ therapies such as vaccines and insulin. Nor should we neglect the colonial natural historical surveys and pest management programmes for empire.\textsuperscript{120} By the interwar years neither the industrial chemist nor the


\textsuperscript{120} Peder Anker, \textit{Imperial Ecology: Environmental Order in the British Empire, 1895-1945} (Cambridge, MA: Harvard University Press, 2001); Michael Worboys, ‘Science and British Colonial Imperialism, 1895-
secondary school science teacher, nor the imperial agricultural or forestry officer was a novelty; they were established roles in a growing technical middle class, about which we know little. A significant proportion of them were women, especially in the biological sciences, though until after WWII marriage usually prevented further employment. Science, one could say, was now a mode of employment, not just an interest, a school subject or a form of belief.121

Associations with new industries such as chemicals, aviation, electricity and radio, increased the ascendancy of science, though it is worth noting that the rate of growth of universities was much lower than for the period 1890-1914. And for some industrialists and politicians a scientific approach to industry seemed to offer an escape from the deep class antagonisms evident from c. 1916 to the failed General Strike of 1926. Alfred Mond, one of the founders of giant chemical firm, ICI, gave his name to plans for corporate rationalisation and constructive engagement with labour -- a centrist programme which could also be seen in parts of the scientific community.122 In the 1920s, Britain, as a victorious power, was no longer threatened by Germany; the challenges and the models for the old country now came increasingly from the USA, not least from its industry and its industrial funding for research.

The 1930s were a different matter, as the depression undermined the legitimacy of laissez faire capitalism and provided a startling contrast between the collapsing liberal powers and the transformed powers of continental Europe: Nazi Germany and the Soviet Union. For some younger academic scientists, as for intellectuals more generally, the 1930s were a decade of mobilisation, theoretical experimentation, and action. Britain produced a remarkable group of scientist-activists – including Lancelot Hogben, Herman Levy, J.D. Bernal, Patrick Blackett, J.B.S. Haldane and Joseph Needham.123 Though they were always a minority, the scientific left of the 1930s were part of a vibrant new ‘Anglo-marxist’ culture,124 and the accounts they wrote of British science and technology proved influential in the 1960s and 1970s.

The Second World War
For WWII as for the Great War, the standard story of British science centres on the drafting of academic scientists into the war effort, now with a particular emphasis on radar, the atomic bomb and ‘operational research’.125 But again this account neglects

1940’ (PhD, University of Sussex 1979); R MacLeod, ed., Nature and Empire: Science and the Colonial Enterprise, Osiris, 15 (2001). And especially, see the article by Michael Worboys on colonial science, in this CUP volume.
122 Werskey, Visible College.
123 Werskey, Visible College; McGucken, Scientists, State and Society; Mayer “‘A combative sense of duty’,” especially 81-3.
125 See Rose and Rose, Science and Society; Angus Calder, People’s War (London: Cape, 1969) chapter 8. See also William McGucken, “The Central Organisation of Scientific and Technological Advice in the United Kingdom during the Second World War,” Minerva, 17/1 (1979), 33-69; Scientists, Society and the
pre-existing military technological organisations, though these were much larger in 1939
than in 1914. In WWII, a small number of academic scientists, plus large numbers
of recent graduates, were recruited into pre-existing research and development programmes,
which were hugely expanded. Most of the famous innovations in military technique
came from state servants and their new recruits, rather than from seconded academics:
radar was developed by government radio experts; the jet engine by civil servants and an
RAF officer, Frank Whittle; and sonar (ASDIC) by naval scientists. Many academics
and young scientists were also recruited into long established projects in aeronautics,
poison gas, explosives, ballistics and so on. In distinct contrast to the USA, the
universities did not become major R&D contractors; military R&D was carried out
almost exclusively in government laboratories and private firms. Universities continued
essentially as teaching bodies, turning out graduates, often on accelerated courses.

The standard accounts also overestimate the role of high profile of academics like Bernal,
Blackett and Zuckerman. They were involved primarily in ‘operational research’ which
was peripheral to the main research and development effort where academic scientists
rarely held the top posts. Though academic scientists came to head the old Woolwich
research department (which would later create the British atomic bomb) and the army
radar effort, newer enterprises such as the Telecommunications Research Establishment
the key radar laboratory) and the Royal Aircraft Establishment remained in the hands of
pre-war scientific civil servants.

Industry was also involved, even in the most ‘academic’ of wartime innovations –
penicillin and the atomic bomb. Consider penicillin, where an initially fruitless discovery
by Alexander Fleming at a London voluntary (charity) hospital, was taken up in Oxford
by Howard Florey in his MRC-funded survey of natural antibacterial substances. The
project was then boosted by war-time funding and transferred to industry for production.
The British pharmaceutical companies and ICI were closely involved and produced
penicillin on a substantial scale, but US universities and companies were able to steal a
march, and establish patents, through their greater experience of large-scale
fermentation. The British bomb project was also conducted both in university
laboratories (with a high proportion of refugee scientists) and in industry – with ICI
taking a leading role; indeed, within government, the project was run by an ICI, Oxford-
trained chemist. This huge project was also later transferred to the USA and Canada,

State: The Social Relations of Science Movement in Great Britain, 1931-1947 (Columbus: Ohio State
126 Paul Crook, ‘Science and War: Radical Scientists and the Tizard-Cherwell Area Bombing Debate in
and Gabrielle Hecht, both pieces particularly focussing on the role of the left. See also the ongoing work by
Maurice Kirby.
127 See Edgerton, Warfare State, chapter 4.
128 G. Macfarlane, Howard Florey: The Making of a Great Scientist, (Oxford, 1979); G. Macfarlane,
Alexander Fleming: the Man and the Myth (Oxford University Press, 1985); Heaman, St Mary’s; Jonathan
where major industrial corporations and the USA Army corps of engineers both played
important roles.

However produced, the results became icons of British brilliance, and they helped give
science and technology a new place in public culture. Science was respected, even
feared. For the MRC, penicillin was strong evidence for the support of basic research
and for national planning; for many others it became a tale of national loss through
failure to control exploitation; and at the end of the war, when the NHS was imminent
and the nationalisation of the chemical industry a real possibility, Fleming’s discovery
was used in defence of British voluntarism.\textsuperscript{130} As never before, Britain saw itself as a
scientific nation, and the arguments for more science in national life, associated
particularly with the scientific left, became truisms. The wartime expansion of research
activity continued into the peace and was linked to a similar growth in development,
indeed they came closer together, as the increasing use of the term ‘research and
development’ suggested. The challenges and models for Britain now lay in the new
superpowers -- the USA and the USSR. Into the early 1960s, British expenditure on
scientific research and development (relative to output) was a good third behind the
superpowers, though well in advance of the former great powers.

The Nationalisation of Research and Development
Most studies of post-war Britain are organised round the ‘rise of the welfare state’, but,
for the promotion of research, \textit{welfare} was less important than \textit{warfare} and the industrial
development that was partly driven by nationalistic economic policies. Imports were
systematically discouraged, and local designs and suppliers sources preferentially used.\textsuperscript{131}
Perhaps the key feature of the post-Second World War years was the dominance of the
national government -- through a greatly expanded military sector together with the
nationalisation of public utilities, key industries such as coal and steel, and the hospitals.
National agriculture was expanded very significantly by direct and indirect subsidy,
including money for scientific research; even in plant breeding, government funding
came to dominate the four important institutions that had in the past received only part of
their income from the state.\textsuperscript{132} And the new Colonial Research Council spent more than
the MRC or the Agricultural Research Council,\textsuperscript{133} partly because of the drive for the better exploitation of raw materials, symbolised by the ambitious African groundnut
scheme of the late 1940s, part of the ‘second colonisation’ of Africa.\textsuperscript{134}

In the first two post-war decades Britain maintained very high research and development
(R&D) spending -- civilian and military, public and private – and compared with the rest

of Western Europe its higher education system was peculiarly oriented towards science and technology. The proportion of national income devoted to R&D was much higher than that of any capitalist nation other than the US, and British businesses were second only to those of the USA in absolute and relative commitment to industrial research.\footnote{135 Edgerton, British Industrial ‘Decline’.} From 1945 to 1974 British scientists won, on average, more than one Nobel Prize each year, a much better record than in the first half of the century. But, for all this strength, who could doubt that the world centre of scientific, technical and medical innovation had passed from Europe to the United States? America, much more than Britain was the model for post-war scientific reconstruction in continental Europe; and it became common for young British researchers to spend time in the USA.\footnote{136 Jean- Paul Gaudilliere, , Inventer la biomedicine: la france , l’amérique et la production des savoirs du vivant (1945-1965), (Paris: La Découverte, 2002).}

But at the end of the war, the scale of British warlike research and development (R&D) hardly diminished as the government committed to new generations of armaments, including nuclear, chemical and biological weapons; demobilisation was minimal. And from around 1950, rearmament brought huge increases in military R&D spending, overwhelmingly in government and industry.\footnote{137 Gowing, Britain and Atomic Energy; Gowing, Independence and Deterrence; Peter Morton, Fire across the Desert: Woomera and the Anglo-Australian Joint Project 1946-1980 (Canberra: Department of Defence, 1989); Edgerton, Aeroplane; S. R. Twigge, The Early Development of Guided Weapons in the United Kingdom 1940-1960 (Amsterdam: Harwood Academic, 1993); Jon Agar and Brian Balmer “British Scientists and the Cold War: The Defence Research Policy Committee and Information Networks, 1947-1963,” Historical Studies in the Physical Sciences, 28 (1998), 1-40; R. Bud and Philip Gummett, eds, Cold War, Hot Science: Applied Research in Britain’s Defence Laboratories, 1945-1990 (Harwood Academic, 1999); Brian Balmer, Britain and Biological Warfare: Expert Advice and Science Policy, 1930-1965 (London: Palgrave, 2001); Lorna Arnold, Britain and the H-Bomb (London: Palgrave, 2001); James Small, The Analogue Alternative: The Electronic Analogue Computer in Britain and the USA, 1930-1975 (London: Routledge, 2001); Edgerton, Warfare State.} As a result, in the mid-1950s some 80% of government R&D, and 60% of all British R&D was military. Though most was done in industry, national laboratories became increasingly important. The civil atomic programme was developed in a new state laboratory at Harwell, while the bomb was designed at the army’s main research laboratory, and then at a new state laboratory at Aldermaston. At Porton Down, work on chemical warfare was supplemented with an important programme on biological weapons.\footnote{138 Robert Bud, The Uses of Life: A History of Biotechnology (Cambridge: Cambridge University Press, 1994).} The aeronautical and electronic laboratories were also expanded. Again and again we find the belief that brilliant Britain could design innovative aeroplanes, nuclear reactors and electronic devices that would leapfrog the more intensive but plodding efforts of the Americans.\footnote{139 Edgerton, Aeroplane; Sophie Forgan, “Festival of Science and the Two Cultures: Science, Design and Display in the Festival of Britain, 1951,” British Journal for the History of Science, 31 (1998), 217-40; Bud, “Penicillin and the New Elizabethans”.} In 1949 Britain clearly considered itself the second great technological power, but the explosion of the Soviet atomic device in that year led to some downgrading of this assessment.

It is sometimes argued that this expenditure on weapons was at the expense of bread and butter civil development, and that Germany and Japan, no longer world powers, were
able to outspend Britain on such R&D; but this common place of commentary is untenable. Industrily-funded research and development boomed from the end of the war, and into the mid-1960s it was absolutely and relatively greater than that of German or Japanese industry. Furthermore, British industry distributed its effort across different fields in much the same way as the Germans and the Japanese.

In medicine too, the role of the central state grew strongly. The National Health Service took over local authority and voluntary hospitals into one national system. University hospitals were now owned by the state, almost all hospital doctors moved onto salaries (though often part-time), and clinical research departments were set up in most teaching hospitals. Many of the new clinical researchers collaborated with the pharmaceutical companies which greatly expanded their research activities; ICI moved into pharmaceuticals, including new anaesthetics -- partly from its experience in the war-time collaborations over fluorine chemistry and penicillin. A wartime committee on medical education proved successful in boosting pre-clinical sciences in Universities, thus strengthening research as well as teaching (but it proved less successful in its advocacy of ‘social medicine’, a discipline meant to incorporate social sciences into clinical medicine and so rescue ‘public health’ from the local authority medical-bureaucrats). The MRC was particularly keen to support biophysics and helped several war-time physicists to enter this new field, so encouraging the x ray crystallography and membrane physiology for which Cambridge and London Universities, especially, were already known. They also funded much more clinical research and helped build up academic departments in teaching hospitals. Some of these departments then collaborated with the pharmaceutical companies, developing antibiotics and then new drugs for psychiatric and cardio-vascular diseases. For the first time, Britain was now a major player in the international drug industry.

---


146 Austoker and Bryder, Historical Perspectives.
The nationalisation of research and development went hand in hand with an incremental nationalisation of the universities. The huge new demand of the state and industry for scientists, engineers, and to a lesser extent doctors, led to a radical expansion of higher education, especially in London and the major civic universities, which were now funded largely by central government. By the 1960s, universal funding for student maintenance as well as fees meant that all universities were, for the first time, overwhelmingly dedicated to full-time residential education geared towards the three-year honours degree (or four in Scotland). By this time the majority of male graduates studied science, engineering or medicine. Whist at the beginning of the century, churchmen, lawyers and doctors had dominated the professional middle classes, by 1940 they accounted for about half the total, their numbers having remained static whilst those of scientists, and especially engineers, had risen rapidly.

State funding for research in universities increased massively, and for academic scientists the 1950s and 1960s were a golden age. Many new fields built directly on war-projects and equipment— from digital computing and radio astronomy to nuclear power and antibiotics— and a self-confident and creative scientific élite moulded the great universities, not least through the experience of administration and command which many young scientists had gained in the war. In terms of public recognition and achievement, perhaps the most famous British developments were in X-ray crystallography applied to molecular biology: from Wilkins and Franklin in London, to Watson and Crick in Cambridge, and to the elucidation of the structures of other large molecules by Perutz, Kendrew and the biochemist Fred Sanger.147 In physics, the acclaimed successes were in theoretical cosmology, and in radio-astronomy – from Manchester’s Jodrell Bank, to the rather different Cambridge work.148 Both these Universities also attracted attention for work on electronic computers. But of course, the public successes were a tiny proportion of the total academic research about which we as yet know very little, historically. Yet there is no doubt that British academic research was enormously productive in the years after the second world war; in the history of almost all disciplines, one has to consider the British contributions.

Ideologues and ideologies

The scientific left of the 1930 were active into the 1940s, before foundering in post-war ‘NATOpolitan’ culture, like most of the rest of this tradition.149 In the three post-war decades, the dominant ideological tone of science, like that of political culture more generally, was broadly social democratic and technocratic, with a particular emphasis on the need for national modernisation programmes. The relative economic decline of Britain, now being dated from 1870s, was commonly blamed on a failure to invest in

147 Chadarevian, Designs for Life.
science and technology, and in C.P. Snow’s ‘two cultures’ polemic and elsewhere, the British political class was presented as aristocratic and amateur -- hostile to science and engineering, careless of economic growth.

This kind of thinking reached its highpoint during the Labour government of 1964-1970; Prime Minister Harold Wilson’s ‘White Heat of the scientific revolution’ is usually taken as the major peacetime technocratic initiative in British history, and one which failed.

It is explicit or implicit in most commentary that Britain’s technocratic tradition, where it existed, was on the left. But a new scientific left -- much less élite and much more critical of science— emerged in the 1960s, notably around the British Society for Social Responsibility in Science. Their key concerns were the abuse of biology (for example in IQ testing), industrial hazards, environmental degradation, and state use of new repressive technologies.

Both these generations of marxist scientists and scholars contributed considerably to the social study of British science, not least its history, from Bernal to Robert M. Young and beyond.

The scientific right is much less studied, though it is clear that anti-technocratic conservation movements were established between the wars, partly to protect the countryside from pylons and creeping suburbia. A liberal critique of planned science was developed from the late 30s, and was associated with post-war opposition to ‘state medicine’. Its ablest ideologue was the Hungarian émigré Michael Polanyi, Professor of Physical Chemistry and then of Social Philosophy at Manchester, and closely associated with classically liberal philosophers and economists such as Friedrich von Hayek. They were profoundly hostile not only to Marxism but also to centrist scientism, and their

---


152 For a different view see Edgerton "The 'White Heat' Revisited: British Government and Technology in the 1960s," Twentieth Century British History, 7 (1996), 53-82.


writings were well supported by the CIA.  Yet there were also powerful technocratic traditions on the right which helped drive nationalistic scientific and technological policies, and certainly the great military-technological effort.

From the late 1960s then, post-war technocratic nationalism came under attack from both wings of politics: from the Left who were antimilitarist, environmentalist and sceptical of pharmaceuticals; and from the neo-liberal economists of the Right who attacked state technology, though only the civil version. The 1970s saw increased scepticism about large-scale civilian programmes, like the Advanced Gas Cooled Reactor and the Concorde; and modernisation through science and technology increasingly lost its appeal to younger generations of intellectuals, influenced by ecological concerns and a more culturally-oriented New Left. As we note below, these attacks did not bring the end of such programmes, but the old triumphalism was gone. And it was the neo-liberal right, rather than the libertarian left which won out ideologically. Indeed by the 1980s, Britain, with the USA, was at the centre of a general ideological, political and economic shift to the right, strengthened by a new economic globalisation and victory in the Cold War.

For many politicians around the world, ‘Thatcherism’ as well as ‘Reaganomics’ became models for new relations between governments, industry and public services. Though she was the first scientist prime-minister (with a chemistry degree from Oxford), Margaret Thatcher was deeply sceptical of ‘social engineering’ and of the professions, including medicine. Her denationalisation of industry – a mixture of privatisation and liberalisation -- went along with a further denationalisation of research. Her advisors were hostile to the planning of science, yet paradoxically the Thatcher years saw a radical centralisation of control over the universities, and a strengthening of central control of state-funded research. The aim was to cut expenditure and to change culture, and in this she succeeded. The old certainties of public service and state-led development gave way to a cult of entrepreneurs, managers and management-consultants which has continued to the present in the public sector as well as the private. State funding for University research remained vital, and the popularity of the NHS protected it from major moves towards private insurance, but cumbersome external assessment mechanisms were imposed on universities and ‘internal markets’ introduced to the NHS. Large-scale philanthropy, especially the cancer charities and the Wellcome Trust, emerged as a major determinant of medical research. The academic scientific community remained generally centrist in its politics and committed to increasing state funding. Indeed in the mid


156 Edgerton, Aeroplane; Warfare State.


1980s, faced with funding cuts, a scientists’ organisation called ‘Save British Science’ renewed the claim that Britain had long been hostile to science and technology.\textsuperscript{159} Thatcherite scientists were rare – an exceptional neo-liberal account of science met with howls of rage.\textsuperscript{160} The scientific élite became increasingly concerned with propaganda for science – by the end of the century Britain had invested in ‘science-centres’ aimed at children, and the bookshops were full of popular science books.

**De-nationalisation and internationalisation**

In a modernising nation, the state was expected to take an increasing role in leading and controlling research and the applications of science and technology – the scientific revolution and state planning were felt to go hand in hand. But slowly, and at first secretly, the viability of national programmes had come to be questioned. In 1958 Britain stopped independent development of nuclear weapons and nuclear reactors for submarines – it depended on the United States, as it also did for long-range missiles. In the early 1960s, congruent with an early attempt to join the European ‘common market’, two large civilian trans-national projects were started – the Concorde supersonic airliner (with France) and the development of a satellite launcher (through a consortium of European nations). They were followed in the mid-1960s and beyond by Anglo-French and European military projects. In ‘pure’ science too, European organisations played important roles – for example, CERN and EMBO.\textsuperscript{161} And by the end of the 1960s it was understood that expenditures on research and development, even civil ones, did not correlate positively with economic growth.\textsuperscript{162}

Nonetheless, in some new fields, for example electronics and computing, new national programmes were developed in the 1970s, and in agriculture the strong state subsidy of a private industry, supported by state and private research, continued to transform productivity. Even in defence, R&D rose in absolute terms in the 1970s and the early 1980s; as a new Cold War took root, the state’s R&D programme was remilitarised. But with the ending of large scale civil development programmes, the fall in defence R&D from the mid-1980s, and the liberalisation and privatisation of government research under Margaret Thatcher, expenditure by government on R&D fell from 0.9% to 0.5% of GDP by the end of the 1990s. The proportion of GDP devoted to R&D peaked at around 2.3% in the early 1960s; in the 1980s and 1990s it drifted downward, to 1.8% in 1999 – levels not seen since the 1950s.

Since the 1980s, the previously assumed relations between national capacity in R&D, national-champion industrial firms, and national economic development shaped by state action have weakened considerably, not least through the continued decline of manufacturing industry. In Britain, more than in most of Europe, privatisation, marketisation, liberalisation, internationalisation, and globalisation have substantially modified the structures and processes of science, technology and medicine, though the


\textsuperscript{161} See Krige and Pestre, eds, *Science in the Twentieth Century*.

\textsuperscript{162} Edgerton, “White Heat”.

35
state continues to fund most university work and the vast majority of health care. In 1984 the Anglo-Dutch firm Unilever bought the Plant Breeding Institute and the National Seed Development Organisation from the government; in 1998, they were sold on to the US firm Monsanto. The former National Research Development Corporation, set up in 1948 to exploit public sector research was privatised in 1992. The atomic weapons establishment, part of the Ministry of Defence, was transferred to a private contractor in 1993. Large scale development of British nuclear reactors was run down, and American designs imported. Privatisation of electricity supply further reduced the civil nuclear programme, which was itself privatised in the mid-1990s. The National Physical Laboratory – that great symbol of state civil science was ‘contractorised’ in 1995, and in 2001 all the military laboratories, with the exception of the nuclear, and the biological and chemical warfare centre at Porton Down were put into QinetiQ plc which was intended for the private sector. Many of the national industrial projects of the 1960s and 1970s were later left to the international market. Generally, the British subsidiaries of foreign multi-nationals performed higher proportions of research, and increasing proportions of the industrial research expenditure came from abroad.

By the end of the 1990s the declinist emphasis on the poverty of British science gave way among elite scientists to an emphasis on the strength of British academic science in comparative terms. This new argument for support, congruent with the emergent anti-declinist accounts, had much evidence in its favour. The MRC remained a major supporter of world-class biomedical research, especially in molecular biology, but other agencies became increasingly important. The Wellcome Trust cut its links with the parent pharmaceutical company and became a major funder of medical research, alongside the cancer charities. Around 2000, it collaborated with government in a widespread renovation of University science facilities. The drug industry saw a series of mergers, and some internationalisation of research, but remained competitive. For medical technology, where Britain was notable for inventions in the 50s and 60s (for example, the CT scanner developed by EMI, and the artificial hip developed by a surgeon, John Charnley), British companies tended to be overtaken by American rivals which were faster to innovate and familiar with their larger and richer markets.

---

163 The micro-chip maker INMOS was sold to the private sector in 1985, and sold on to a non-British firm; the British mainframe computer industry, brought together by state action in he 1968 as the national champion ICL, was sold to STC in 1984, and in 1990 to the Japanese firm Fujitsu. Campbell-Kelly, ICL: M. McLean and T. Rowland, The INMOS Saga – a Triumph of National Enterprise (Pinter, 1985).


In Britain around 2000, the biomedical sciences seemed increasingly central to economic policy as well as health. In universities, they easily rivalled the physical sciences which had long dominated the science faculties. But they were also controversial, Britain was known worldwide for the epidemic of ‘mad cow disease’ in the last years of the Conservative government, and New Labour was rocked in 2001 by a major outbreak of Foot and Mouth Disease. Both helped build a public suspicion, which is also evident in recent British debates over vaccination, genetically modified organisms, and the retention of bodily organs in hospitals. Large increases in funds for medicine, not least through charities, have accompanied continued public scepticism and a loss of authority by medical professionals. Doctors and the new ranks of managers and health economists have pushed for ‘evidence-based medicine,’ but in an increasingly litigious and consumerist context. In medicine, the concerns are usually raised by the patients groups which have proliferated from the 1970s; for environmental issues the chief propagandists are international charities such as Greenpeace or Friends of the Earth.

Over the last decade then, public discussions about science in Britain have been less about national economic growth or defence, and more about the possibilities and threats of informatics and molecular medicine. The politics of science are increasingly public and international; but no longer, if ever, could one easily line up science versus anti-science, though this is how the science lobby sometimes portrays its problems. Increasingly, we would argue, science must be understood as multiplex, and projects examined for the different values they incorporate. The critique of science can then be much more than a demand for more (or less); it could be about of choices between projects and between different kinds of science-politics, about the development of STM, about ongoing history.

As we have tried to show, the older historiographies of British science often relied uncritically on arguments made by researchers to demand more funds. Those arguments were often about industry and military might. But much of the industry and the might have now departed, and newer debates are concerned more with effects of science than with levels of investment. At the end of the twentieth century, most of Britain’s opinion-formers have barely known the Empire, or ever felt Britain to be a Great Power. They grew up in a world when economic status was insecure, and they now see a world where economic success is spread among many nations, east and west. As globalisation and economic communities weaken the nation-state, as the priorities of medicine are debated and those of ‘economic development’ come under environmentalist scrutiny, we will need more varied and more international histories. In these international histories, Britain will have a major place; for over the span of this article -- from the global Empire to its end, and across a wide range of political and institutional regimes -- Britain has remained among the most creative of scientific nations.

END