

Starry Eyes and Harsh Realities: Education, Research, and the Electrical Engineer in Europe, 1880-1914

Robert Fox
Oxford University
and
Anna Guagnini
University of Bologna

In the age of science-based industry, it is tempting to suppose that the quality of a nation's scientific education and research and the prosperity of her manufacturing sector are two sides of a single coin. Of the case-histories that are commonly advanced to support this view, none appears more compelling, at first sight, than the extraordinary development of the modern electrical industry about the turn of the nineteenth century. In a period when a main cutting-edge of electrical technology was in the new and complex field of high-voltage long-distance transmission, it was not difficult for university departments of physics and engineering and advanced technical schools to portray themselves, and be accepted, as founts of technological success. Between the 1880s and 1914, in fact, laboratories and lecture theatres came to be regarded as pre-requisites for industrial strength, to be fostered, fought for, and flaunted as a matter of supreme national interest.

It is only in recent years that the belief in the role of science in determining a nation's success or failure in electrical technology — or, for that matter, in any modern technology — has been subjected to serious reappraisal. It is already clear from this rethinking that the vitality of the German or the American electrical industry and the muted performance of, say, Britain and France cannot be explained solely or even primarily as the result of a differential commitment to

advanced education and research. Leslie Hannah, I.C.R. Byatt, and, in a comparative international perspective, Thomas Hughes have all contributed to elucidating the involved mosaic of circumstances that constrained the growth of electricity supply systems in Britain about 1900¹. Likewise, Peter Hertner has unravelled the intricate financial structures that allowed German companies to invade European markets for electrical equipment from the Mediterranean to Scandinavia². And Albert Broder has insisted on such decisive factors as tariff and patent legislation, which made it trivially easy for American and German electrical companies to secure a dominant position in both marketing and manufacturing in France from the 1880s³.

In contexts of such complexity, the interaction between science and industry in the electrical sector was anything but simple or direct. Yet the impact of science can plainly not be discounted, and it remains a central problem, for historians, to determine not whether but how the academic world of electrical science and engineering affected and was affected by industrial practice. In this paper, we tackle part of this more general question, by asking what correlation, if any, there was between the evolution of the relevant areas of some of the main European systems of higher education and research and the divergent national profiles of performance in electrical technology between 1880 and 1914.

Our discussion rests on a fundamental chronological distinction between two phases separated by a watershed coinciding roughly with the International Electrical Exhibition in Frankfurt in 1891. Through

¹ Leslie Hannah, *Electricity before Nationalisation. A Study of the Development of the Electricity Supply Industry in Britain to 1948* (London, 1979); Ian C.R. Byatt, *The British electrical industry, 1875-1914* (Oxford, 1979); and Thomas P. Hughes, *Networks of Power. Electrification in Western Society, 1880-1930* (Baltimore and London, 1983), especially chapters 9 and 12.

² Peter Hertner, 'Il capitale tedesco nell'industria italiana fino alla prima guerra mondiale', in: Bruno Bezza (ed.), *Energia e sviluppo. L'industria elettrica e la Società Edison* (Turin, 1986), pp.213-56.

³ Albert Broder, 'La multinationalisation de l'industrie électrique française, 1880-1931', *Annales ESC*, 39 (1984), pp. 1020-43.

the 1880s and early 1890s, there was an enthusiasm for the applications of electricity that resulted in the virtually simultaneous creation of new courses in institutions of higher education throughout Europe. After Frankfurt, by contrast, there was a far greater diversity between different countries in both the quality and the quantity of the courses and material facilities that were available for the study of electricity. It is essential to our argument that this new disparity in educational provision should be seen as distinct from the ubiquitous expansion of the 1880s, and that it should be interpreted more as a reflexion than as a root cause of the process in which Germany and, to a lesser extent, Switzerland inexorably outstripped their European rivals in the field of electricity in the thirty years or so before the first world war. As we shall argue, Germany's capacity to train substantially more engineers and industrial scientists than other countries from the 1890s may very well have been crucial in allowing her to consolidate and stretch her lead in electrical technology: in this sense, it was an important enabling mechanism in the second of our two periods. But it was a mechanism that cannot be invoked as an explanation of how the lead was established in the first place. That explanation would take us far beyond the confines of this discussion, although we do venture a brief comment towards the end of our paper.

Seizing the opportunities: physicists and electricity in the 1880s

With respect to the period before Frankfurt, historians have generally seen the first international electrical exhibition, held in Paris in 1881, as marking the dawn of the modern age of electricity. It was at this exhibition that Thomas Edison launched his incandescent lamp in Europe, and it was here that an intrigued public first glimpsed the extent of the possible applications of electricity, ranging from Siemens' electric tram to the «théatrophone» that transmitted the music of the Opéra several hundred yards to listening points in the Palais d'Industrie⁴. The impression was profound. Installations,

mainly for lighting, proliferated, and during the 1880s generating stations became a feature of virtually every sizeable town in Europe, and in the USA. The pattern, it must be said, was patchy, and it showed no systematic correlation with the state of the local economy. Certainly, the prosperity and advanced state of a region's industry were not prerequisites for the appearance of the first electrical supply systems. Such systems sprang up almost simultaneously — at least on a temporary basis — in countries as far apart as Britain and Roumania and France and Hungary, and they were soon to be found in any country that sought to proclaim its commitment to a technocratic future.

If only because it was so visible, the new application of electrical power to lighting attracted feverish attention from the moment the 1881 exhibition opened. But while the more enthusiastic practitioners and shareholders were sustained by their conviction that electricity embodied progressive, modern-minded values (a conviction that has had its echoes ever since in many historical studies), more critical contemporaries viewed the path of the electrical enterprise as a decidedly stony one, strewn with failures, inflexibility, and high costs. They also saw that the inherent technical difficulties were damagingly compounded by economic ones, in particular by the crisis that worsened dramatically in the early weeks of 1882 and continued to suppress confidence through the 1880s and on into the mid-1890s. In these years, the popular French writer and artist Albert Robida could look ahead to a mid-twentieth century in which electricity — «la Grande Esclave» — would be at the heart of every aspect of life⁵. But, in reality, about 1890 there was little hard evidence to buttress Robida's imaginative vision. Electricity still made only

⁴ Robert Fox, "Edison et la presse française lors de l'Exposition Internationale d'Electricité de 1881", in: Fabienne Cardot (ed.), *Un siècle d'électricité dans le monde, 1880-1980* (Paris, 1987), pp.223-35, and "Campaigning for Edison: the hidden face of technology transfer at the Exposition Internationale d'Electricité, 1881". [*Typescript now being prepared for publication*].

⁵ Albert Robida, *Le vingtième siècle. La vie électrique* (Paris, 1892), especially pp.3-5. Robida's vision of the glorious future of electricity had already been evident, though less forcefully, in his earlier volume, *Le vingtième siècle* (Paris, 1883).

a modest contribution to the economies of even the most highly electrified nations, and it was to be another decade or more before it became a major source of domestic and industrial power for purposes extending significantly beyond lighting.

Since the justification for the early excitement surrounding electrical power materialized so haltingly, the intensity of the starry-eyed vision of the 1880s and the relative uniformity of its consequences in the early developments in advanced education and research in electricity appear remarkable. Why should courses and electrical laboratories have begun to proliferate at a time when electricity was still, in economic terms, a modest, if glamorous, sector, and when both the short-term and long-term profitability of electricity was open to serious doubt?

Any explanation must take account of the fact that, by 1880, low-current electricity was already an established speciality in the discipline of physics and one that had had spectacular industrial applications, above all in telegraphy. Ever since the laying of the first submarine cables across the English Channel in 1850 and the Atlantic in 1866, physicists had made particularly notable contributions to the scientific problems arising from the obfuscating retardation of telegraphic signals. As professor of natural philosophy at the University of Glasgow, William Thomson had been a pacemaker⁶. He had branched out from an involvement in the first, unsuccessful transatlantic cable project of 1857-8 to develop both an academic and a commercial involvement in applied electricity, and his laboratory at Glasgow had become what was in effect a pioneering centre for teaching and research in electrical technology. In it, students who showed the necessary interest and ability were introduced not only to the use of instruments and the practice of experimental research, but also to investigations connected specifically with Thomson's business activities. By 1870, an average of thirty students a year attended

⁶ M. Norton Wise and Crosbie Smith, "Measurement, Work and Industry in Lord Kelvin's Britain", *Historical Studies in the Physical and Biological Sciences*, 17 (1986), pp.146-173, and *Energy and Empire. William Thomson, Lord Kelvin, 1824-1907* (Cambridge, 1989), especially chapters 13 and 19-20.

Thomson's laboratory classes, and about a dozen of them were engaged in work concerned more or less directly with the applications of electricity.

By the 1870s, the same strong orientation towards electricity (mainly telegraphy and the calibration of measuring equipment) had made its mark on physics laboratories in virtually every European country. In the process, a growing concern with the instruction of students in experimental techniques had made laboratory teaching, in particular in the techniques of precise measurement, a routine part of the formation of physicists⁷. The fruits of the trend, in the form of new or refurbished laboratories and of new chairs, were already substantial before 1880, but they did little to dampen the physics community's campaign for even better facilities: certainly, in 1880, the campaign was seen as still having a long way to go. In these circumstances, the new departures in electricity that were presented at the 1881 exhibition came as an unheralded godsend, in Germany as everywhere else. Almost providentially, the exhibition lent new strength to a case, based largely on the utility of their work, that physicists had been advancing for a quarter of a century with vigour and conviction, though with rather less success than they believed they deserved.

When the rapid spread of electric lighting and these elements in the «pre-history» of the academic development of electricity are taken into account, the readiness of institutions of higher education to assimilate the new form of the speciality, with its distinctive emphasis on lighting and on high currents, after 1881 becomes less puzzling. As David Cahan has argued, the accelerated growth of physics departments in the German universities from the 1880s rested largely on long-familiar claims concerning the bearing of applied physics, and of electricity in particular, on the national interest.⁸ In England too,

⁷ Graeme Gooday, "Precision measurement and the genesis of physics teaching laboratories in Victorian Britain", *The British journal for the history of science*, 23 (1990), pp.25-51.

⁸ David Cahan, *An institute for an empire. The Physikalisch-Technische Reichsanstalt 1871-1918* (Cambridge, 1989), chapter 1.

the improvements that were made in the provision for teaching and research, notably through the creation of chairs and laboratories, owed a great deal to earlier activity and agitation. In London, two of the main beneficiaries of the 1880s, George Carey Foster and William Grylls Adams, respectively professors of experimental physics and natural philosophy at University College and at King's College, had enthusiastically followed the trends that had been in train since the mid-century. Both of them devoted a substantial part of their courses to instruction in the manipulation of electrical apparatus and in the use of instruments for the measurement of electric currents and resistance. It must be said that the laboratory facilities which they offered from the 1860s were limited, especially for teaching, but their pedagogical objectives were clear, and through the 1870s they fought for and secured distinct improvements, especially at King's College.⁹

The vision, which Foster and Adams shared, of the importance of laboratory instruction in electricity was matched by the perceptions of students, most of whom before 1880 were attracted to physics by the electrical content of the courses. In London, candidates preparing for entry to the Indian Civil Service's telegraphic service, created a particularly brisk, if irregular, demand for short training courses in telegraphy. Despite their status as occasional students, they provided the physics laboratories at both University College and King's College with a profitable clientele and, no less importantly, a visible justification for the expenditure on fitting out and equipment.

With the ground so well prepared by courses of the kind offered by Foster and Adams, the more substantial move towards electricity that

⁹ In 1866, shortly after his appointment to the chair, Foster set up a small teaching laboratory, in which he gave instruction in the use of scientific instruments, with special reference to precision measurement and electricity; see A. H. Fison, "George Carey Foster", *Transactions of the Chemical Society*, 115 (1919), 412-27, and H. H. Bellot, *University College, London, 1826-1926* (London, 1929), pp.311-12. At King's, as professor of natural philosophy from 1865 to 1905, Adams complemented his lectures with laboratory classes in which the emphasis was on precision measurement in low-current electricity. Adams's laboratory was open to students by 1869; see Francis J. C. Hearnshaw, *A Centenary History of King's College 1828-1928* (London, 1929), pp.289-92.

occurred in physics departments during the 1880s presented few difficulties. The reputation of the Cavendish Laboratory in Cambridge for its work on electrical standards was quickly established in this period. And elsewhere applied electricity began to appear as a distinct subject in many physics syllabuses. A notable instance was that of Owens College, Manchester, where the election of Arthur Schuster to the Langworthy chair of physics in 1887 was followed by a considerable expansion of the subject, including the launching, in 1889, of a course leading to a certificate in the technical applications of electricity.¹⁰

Even in the Italian universities, where experimental physics had not yet recovered from a long period of stagnation, the advances in electrical research, both theoretical and applied, clearly inspired the work of some younger academics such as Antonio Pacinotti in Pisa and Augusto Righi in Padua. In a fashion that mirrored developments in other countries, a steadily growing proportion of the syllabuses in physics came to be devoted to electricity and its applications, even though the lack of research facilities stifled attempts to move beyond what remained, in most cases, essentially theoretical instruction.¹¹ It is true that by the end of the century, new laboratories did exist, but, by then, electricity was a less effective magnet for attracting either funding or students to physics departments than it had been in the 1880s; schools and departments of engineering had now established themselves as more natural settings for the applied aspects of the subject.

It would be impossible to deny that the pace of reorganization in physics departments varied from one national context to another and that the patterns of development were coloured, to some extent, by local conditions. In France, for example, the improvement in the

¹⁰ Although a physical laboratory was established at Owens College as early as 1870, electricity remained a minor part of the programme until Schuster's arrival in 1884 (three years before his appointment as professor). See Robert H. Kargon, *Science in Victorian Manchester. Enterprise and Expertise* (Manchester, 1977), pp.214-37.

¹¹ Barbara Reeves, 'Le tradizioni di ricerca della fisica italiana nel tardo diciannovesimo secolo', in: Vittorio Ancarani (ed.), *La scienza accademica nell'Italia post-unitaria. Discipline scientifiche e ricerca universitaria* (Milan, 1989), pp.53-95.

facilities for teaching and research in electricity owed much to the broader process of reinvigoration in the faculties of science (as in other faculties) that resulted in the «new» Sorbonne of the 1880s and in new physics laboratories in Bordeaux, Toulouse, and elsewhere, all dating from the 1880s and 1890s.¹² Yet it is also important that such local factors should not be exaggerated or seen as more exceptional than they really were. Wherever there were signs of a readiness to extend instruction in the applied aspects of physics, the air of intellectual excitement and economic relevance which the rhetoric managed to convey bore fruit of conspicuous benefit to the study of electricity. The results were evident not only in the increased investment in physical laboratories, with what had now become a routine provision for electrical measurement, but also, and no less importantly, in enhanced enrolments in physics courses. Owens College is typical in this respect. There, the number of students attending the course in the physics laboratory rose from a disappointing 13 in 1875 to 62 in 1885; ten years later it reached a peak of 183.¹³

Of course, the opportunity of specializing in electricity was not the only attraction. Students of medicine and chemistry were often an important category among those who attended laboratory classes in physics, and even of the students who graduated in physics, only a minority actually went on to careers in the new world of the electrical supply companies or the manufacturing sector. Nevertheless, it is beyond question that the inherent interest of electricity and its associations with progressive values served as

¹² Of an extensive literature on the renewal of the French faculties of science under the Third Republic, see, for example: George Weisz, *The Emergence of Modern Universities in France, 1863-1914* (Princeton, N.J., 1983), especially chapter 5; Robert Fox, 'Science, the University, and the State in Nineteenth Century France', in: Gerald L. Geison (ed.), *Professions and the French state, 1700-1900* (Philadelphia, 1984), pp.66-145; Harry W. Paul, *From Knowledge to Power. The Rise of the Science Empire in France, 1860-1939* (Cambridge, 1985), especially chapter 4; and Mary Jo Nye, *Science in the Provinces. Scientific Communities and Provincial Leadership in France, 1860-1930* (Berkeley, Ca., 1986).

¹³ *The Physical Laboratories of the University of Manchester. A Record of 25 years' Work* (Manchester, 1906), p. 1.

a powerful stimulus to the growth in student numbers. They also had more distant consequences in the work of several physicists who, through the 1880s and beyond, went on to practice as engineers and make signal contributions to electrical technology. The cases of John and Edward Hopkinson, who both studied physics at Owens College and then were wranglers in the Mathematical Tripos at Cambridge before turning to engineering, make the point very well.¹⁴

The response of the engineers

Although the initial running was made by physicists, academic engineers too perceived the richness of the opportunities offered by the enthusiasm for electricity. But the engineers' strategy tended to be different from that followed in departments of physics. Whether they were in universities or university colleges (as was usually the case in Britain), in special schools attached to the universities (as in the case of Turin), or in quite separate advanced technical schools (such as the *Technische Hochschulen* in Germany or the *Ecole Centrale des Arts et Manufactures* and the *Ecole Municipale de Physique et de Chimie Industrielle* de la Ville de Paris in France), engineers balanced their ennobling assertion that they were there to teach the «scientific principles» underlying industrial techniques with the more easily saleable claim that they offered something the universities could not provide: a practical introduction to the techniques themselves. The consequences of that claim are to be seen in the emphasis that engineering curricula placed on workshops (as opposed to laboratories) and in the decidedly marginal position that research occupied in engineering schools and departments until after 1900.

A number of other factors contributed to the distinctive manner

¹⁴ In addition, while at Cambridge, both John and Edward Hopkinson took the degree of Doctor of Science (in Branch VI: «Electricity treated mathematically») in the University of London. See James Greig, *John Hopkinson. Electrical engineer* (London, 1970), and the obituary notice of Edward Hopkinson in *Proceedings of the Institution of Mechanical Engineers*, 1 (1922), 360-1.

in which academic engineering assimilated electricity. One was the general tide of expansion and reform in higher technical education that was running strongly throughout Europe by the 1880s, creating an openness to technological specialities. Another, far less favourable, was the relatively low level of the pre-existing interest in electricity among engineers (in marked contrast with that among physicists). But the most potent influence was the change, evident since the 1850s, in the main focus of engineering. The traditional emphasis of the early nineteenth century on civil engineering had given way to a new concern with mechanical engineering, with unmistakable consequences for the place that electrical technology came to occupy in engineering curricula and the manner in which it was taught.¹⁵

Virtually everywhere, in fact, electrical technology, as taught by engineers, was closely associated with mechanical engineering, and virtually everywhere the association was a successful one. It enhanced the value of the instruction by allowing the mechanical engineers' established emphasis on practice and machines to be directed, in a very fruitful way, to the developing areas of high currents, transmission, and the design of electrical machinery. Nowhere was this more evident than in Germany. There, in 1882, the *Technische Hochschule* of Darmstadt established the first specialized institute and chair of electrical technology in the world, with a laboratory and workshop for the instruction of students.¹⁶ But even in this well-known case, both appointments and all facilities remained an integral part of the section of mechanical engineering. The syllabus of the four-year course in *Elektrotechnik* gave prominence to the study and design of a wide variety of machinery, which complemented less distinctive work — on electrical measurement for example — that

¹⁵ Hughes, *Networks of Power*, op. cit. (note 1), pp. 140-60, and Wolfgang König, "Elektrotechnik - Entstehung einer wissenschaftlichen Disziplin", *Berichte zur Wissenschaftsgeschichte*, 10 (1987), 83-93.

¹⁶ For an accessible chronology of developments at the Technische Hochschule of Darmstadt, see Marianne Viefhaus, "Chronik zur Entwicklung der Technischen Hochschule Darmstadt", in: H. Bohme (ed.), *100 Jahre Technische Hochschule Darmstadt. Jahrbuch 1976-77* (Darmstadt, 1977), pp. 13-30.

might have been found in courses offered by most departments of physics.

After 1900, as the discipline of electrical engineering grew, certain schools and departments were to opt for a greater degree of separation between their electrical and mechanical interests, but the unified approach remained common until well into the twentieth century. There were outstanding examples of this in London (where William Ayrton's teaching and research in electrical engineering at the Finsbury Technical College and, later, the Central Institution were strongly influenced by his association with the mechanical engineer John Perry¹⁷), the *Technische Hochschule* of Berlin (where specialization in *Elektrotechnik* was only possible in the last of the four years of the course), and the *Eidgenössische Technische Hochschule* (ETH) of Zurich. At the ETH, some electricity had been taught in Friedrich Weber's course on technical physics as early as 1876, but the course was part of a single programme embracing both mechanical and electrical engineering until 1913, and it was only in 1922 that a separate department of electrical engineering was created.¹⁸ Likewise, at the *Ecole Centrale des Arts et Manufactures* in Paris, electricity was just one element in a general three-year course dominated by mechanical engineering, and it remained so even after the opening of a specialized electrical laboratory in 1894 (ten years after the creation of a *maîtrise de conférences* in electricity, the first in France, in 1884).¹⁹ Significantly, in a notable case in which the easy interaction between electrical and mechanical engineering was not

¹⁷ On the context of the collaboration, which had important consequences for the preservation of a good deal of common ground between the three-year certificate courses in electrical engineering and mechanical engineering, see Dominic Jordan, "The Cry for Useful Knowledge: Education for a New Victorian Technology", *Proceedings of the Institution of Electrical Engineers*, 132 (1985), 587-601, and William H. Brock, "Building England's First Technical College: the Laboratories of Finsbury Technical College, 1878-1926", in: Frank A. J. L. James (ed.), *The Development of the Laboratory. Essays on the Place of Experiment in Industrial Civilization* (London, 1989), pp.155-70.

¹⁸ Ernest Dunner et al., "Die Abteilung für Elektrotechnik", in: *Eidgenössische Technische Hochschule. 1855-1955. Ecole Polytechnique Fédérale* (Zurich, 1955), pp.424-43.

¹⁹ Léon Guillet, *Cent ans de la vie de l'Ecole Centrale des Arts et Manufactures 1829-1929* (Paris, 1929), pp.97 and 122-3.

possible — that of the *Ecole Municipale de Physique et de Chimie Industrielle* in Paris, which offered no teaching in *mécanique appliquée* — the implications for the effective preparation of electrical engineers were seen as grave.²⁰

Clearly, in such a brief survey, we cannot hope to be comprehensive: the evidence of successful new departures in the teaching of electrical technology in the context of engineering schools and departments in the 1880s is just too abundant. It is a mark of the strength of the movement that even when governments, municipalities, and other public bodies failed to take the initiative, private funding was seldom hard to find. Support of this latter kind tended to be directed to the provision of specialized short courses annexed more or less loosely to the existing curricula. The most admired example was that of the Institut Montefiore, an independent institution opened in Liège in 1883 to provide an advanced one-year course in electrical technology for graduate engineers and final-year students at the University of Liège.²¹ By comparison with a German *Technische Hochschule*, the Institut Montefiore was small and selective: in 1890, it had just 14 pupils, and even ten years later this figure had risen to only 90. But it shared the primary concern of the *Technische Hochschulen* with conveying immediately usable expertise, mainly for the burgeoning sector of electric lighting and, in due course, traction.

It may be thought unnecessary to discuss in any detail why the Institut Montefiore should have been implanted, even at such an early stage, in a densely populated region that offered a context rich in opportunities for pupils and investments; the explanation seems blindingly obvious. But, as we have indicated, it is essential to our perception of the strikingly diffused development of electrical

²⁰ Charles Lauth, *Rapport général sur l'histoire et le fonctionnement de l'Ecole Municipale de Physique et de Chimie Industrielles* (Paris, 1900), pp.30-1.

²¹ *Institut électro-technique Montefiore. Annexe à l'Université de Liège. But, programme, conditions d'admission* (Liège, 1886). The founder of the Institut Montefiore, Georges Montefiore, was a leading international industrialist. The company of which he was a partner, the Société Vieille Montagne, was Europe's largest producer of zinc, with interests in France and Italy as well as in Belgium.

instruction in the 1880s that we should question whether the new courses and institutions of that decade can be interpreted as simple responses to local economic environments. The initiative at the Institut Montefiore does nothing to diminish our scepticism. For when the institute is viewed in a broader international context, it seems to have been not so much a product of the uncommonly favourable economic circumstances that prevailed in a heavily industrialized Belgium as just one of a number of institutions with broadly similar purposes and curricula that emerged successfully in widely diverse national and regional contexts.

The point is illustrated by a comparison between Belgium and the very different case of Italy. Although Italy was only just beginning to modernize her economy after a long period of stagnation, innovations in the teaching of electrical engineering came almost as rapidly there as they did in Liège. By 1887, an institute for electrical technology, the *Istituzione Elettrotecnica «Carlo Erba»*, had been attached to the Politecnico of Milan, and one year later the *Scuola Superiore di Elettrotecnica* was opened as a specialized section of the *Museo Industriale* of Turin.²² Following the pattern of the Institut Montefiore, teaching at both Milan and Turin took the form of one-year courses for students who had already completed engineering studies. The complementary course in applied physics (in effect, electrical engineering) that was introduced in the faculty of mathematics and physics at the University of Rome in 1888 was a similar innovation.

After Frankfurt: opportunities and realities

Remarkable though the growth in facilities for teaching and research in electrical technology was in the 1880s, it was dwarfed by the expansion that got under way in the wake of the hugely successful

²² Anna Guagnini, "The formation of Italian electrical engineers: the teaching laboratories of the Politecnici of Turin and Milan, 1887-1914", in: Cardot, *Un siècle d'électricité dans le monde, op. cit.* (note 4), pp.283-99 (288-96).

Frankfurt exhibition — the *Internationale Elektrotechnische Ausstellung* — of 1891. If any eyes had become jaded by a surfeit of enthusiasm for electricity in the 1880s, they were soon as bright as ever. The main source of the renewed excitement was the evidence of the feasibility of the transmission of power over long distances. The possibility of long-distance transmission had first been demonstrated by the French engineer Marcel Deprez at the *Munich Electrical Exhibition* of 1882, but it was repeated at Frankfurt on a far grander scale, over a distance three times as great (175km as opposed to 57km). Far more importantly, it was repeated using alternating current, instead of the direct current used at Munich, at a voltage so high — 25000 volts — that efficiency and economic profitability soared. Now at last, electricity as a source of motive power in manufacturing and mass transport, and not simply for lighting, became a reality. As contemporaries sensed and as events over the next decade were to confirm, a new age in electricity had begun.

The surge in enrolments in courses of applied electricity that occurred after 1891 and the creation of a second generation of courses and institutions have to be seen, therefore, not as natural, evolutionary developments from the educational innovations of the 1880s but as responses to a quite distinct wave of confidence. As in the 1880s, the surge had its manifestations throughout Europe. However, it was during this second phase of expansion, from the 1890s, that the divergences in educational provision between countries suddenly, and for the first time, became very marked indeed. It was now, but only now, that the gap in facilities between Germany and Switzerland on the one hand and the countries in the slow lane of technological and economic development on the other began to widen.

The *Technische Hochschule* at Berlin and the ETH in Zurich were two of the most influential pacemakers. Both institutions had their premises for mechanical and electrical engineering refitted on a grand scale, with new posts to match, including no fewer than three full chairs in branches of electrical technology at the ETH, all created between 1895 and 1905.²³ But they were not alone. By 1895, the existing departments of electrical technology at the *Technische*

Hochschulen of Darmstadt and Hanover had moved to new premises with the handsomest of laboratories: at Darmstadt 350,000 marks were spent on the Elektrotechnische Institut between 1892 and 1894.²⁴ At about the same time, new or enlarged and restructured electrical departments were inaugurated at Aachen, Munich, Stuttgart, and Karlsruhe, again with splendid laboratories.²⁵ Now, the contrast with Italy could hardly have been more striking. The growth in the demand for places in advanced technical education, especially in Turin, Milan, and Rome, resulted in hugely overcrowded laboratories, with unhappy consequences for the quality of the training that could be offered. At the Politecnico of Turin, for example, in 1897, 101 students were crammed into an electrical laboratory originally intended for 35, at time when the *Technische Hochschule* in Berlin was coping with more than ten times that number.²⁶

In another country in the slow lane, France, the response at the comparable level was more determined than in Italy. In 1894, the *Ecole Supérieure d'Electricité* was founded in Paris to provide

²³ *Festschrift zur Freier des fünfzigjährigen Bestehens des Eidg. Polytechnikums* (2 vols., Frauenfeld and Zurich, 1905), vol. 1, pp. 353-4. On the investment in facilities in Berlin, in particular for a new electrochemical laboratory opened in 1894, see *Chronik der Königlichen Technischen Hochschule zu Berlin, 1799-1899* (Berlin, 1899) pp. 190-1.

²⁴ Wilhelm Lexis (ed.), *Die technischen Hochschulen im Deutschen Reich*, vol. 4, part 1, of Lexis (ed.), *Das Unterrichtswesen im Deutschen Reich* (Berlin, 1904), p. 284.

²⁵ *Ibid.*, pp.209, 231, and 254. Through the later 1890s, investment in the facilities for electrical technology continued at an undiminished pace. By 1903, a further 500,000 marks had been spent on Darmstadt, and a new building for the Elektrotechnische Institut at Dresden had been erected at a cost of 826,000 marks; see *ibid.*, pp.242 and 284.

²⁶ At the Technische Hochschule in Berlin, the total number of students enrolled for the four-year course (embracing mechanical as well as electrical engineering) rose from 395 in 1890 to 915 in 1895 and finally 1532 in 1900. At the ETH, the corresponding figures (also for a unified four-year course in which electrical engineering was only a part) were 210 (in 1890), 323 (1895), and 380 (1900). It is interesting to contrast these figures with the far more modest ones at the Central Institution in London, where the total number of students, spread in this case over three years, stood at 75 in 1890 and rose to only 88 and 99 respectively in 1895 and 1900. Cf. also the small numbers of students graduating from the French institutions that are discussed in the next paragraph.

advanced one-year courses, on the Montefiore model, for engineers who already held the diploma of an engineering school or the equivalent; within a decade, after a slow start, about fifty students a year were graduating with the school's *diplôme d'ingénieur-électricien*.²⁷ That provision, made privately by the Parisian *Société Internationale des Electriciens*, was significantly extended, about the turn of the century, by the creation of three Instituts électrotechniques attached to the faculties of science at Grenoble, Nancy, and Lille and, in 1908, by the establishment of a fourth at the faculty of science in Toulouse; between them, these four institutes were producing about 250 qualified electrical engineers a year on the eve of the first world war (compared with about fifty a decade earlier). In all four cases, they had become powerful, even dominant, forces in the faculties with which they were associated. Despite numbers of students that were never large by German standards, they appeared to envious colleagues as menacingly voracious devourers of funds, both for teaching and for the laboratories and workshops, chiefly for testing and calibration, which they housed.

The developments in France, as in Britain (where departments of electrical engineering were created in several of the new provincial university colleges), represent for us a middle course. Their reactions appear resolute and fruitful by comparison with Italy's but still muted when they are set beside the spectacular expansion that occurred in Germany. Contemporary accounts made much of the contrast. The official catalogue of the German exhibits at the universal exhibition in Paris in 1900 attributed the success of the electrical industry in Germany to, above all else, "the profound scientific training of the German engineer" and to the vast system of higher technical education

²⁷ On the advanced training of electrical engineers in France between the 1890s and the first world war, see André Grelon, "Les enseignements de l'électricité" and "La formation des hommes: du tournant du siècle à la première guerre mondiale", in: François Caron and Fabienne Cardot (eds.), *Histoire générale de l'électricité en France* (Paris, 1991), vol. 1, pp.254-92 and 802-49, and Robert Fox, "France in perspective: education, innovation, and performance in the French electrical industry, 1880-1914", in: Robert Fox and Anna Guagnini (eds.), *Education, Technology and Industrial Performance in Europe, 1850-1939* (Cambridge and Paris, 1993), pp. 201-26.

in which he was formed.²⁸ In other contexts, throughout Germany, the grandeur of the facilities in the *Technische Hochschulen* and the number of students they prepared were likewise paraded with unconcealed pride, though for reasons only distantly related to industrial need. Laboratories, in particular, were displayed, and acknowledged, as guarantees of the intellectual excellence of what was on offer. They stood as symbols, proclaiming not only the triumphs of German technological genius but also, and more immediately, the rise of the *Technische Hochschulen* as indispensable centres of advanced teaching and research. In doing so, they helped to justify the accolade that the schools eventually received between 1899 and 1901, when their struggle for parity of status with the universities was finally won in the famous series of decisions that gave them the right to grant doctorates in technological subjects, first in Prussia and then in the rest of the Empire.

In pointing to these diverse goals and suggesting that a purely economic explanation for the heavy investment in the *Technische Hochschulen* in the quarter of a century before the first world war is insufficient, we are not seeking to dissociate the schools totally from the parallel growth of the German electrical industry. It was, after all, the prosperity of the industry that helped to create the sense of opportunity for expansion and enhanced status which the champions of the *Technische Hochschulen* realized so successfully. And it was a similar sense of opportunity which enticed students in rapidly increasing numbers from 1890. Between then and 1901, the number of students in the nine *Technische Hochschulen* tripled to over 16,500, a rate of growth greater than anywhere else in Europe and greater than could be explained simply by reference to the articulated demands of industry.²⁹

The consequences of the expansion in Germany were to be profoundly important, though only from the later 1890s, when the long period of economic recession finally gave way to the new

²⁸ *International Exposition. Paris 1900. Official catalogue of the German Empire* (Berlin, 1900), p.172.

²⁹ Lexis, *Die technische Hochschulen*, op. cit. (note 24), p.46.

confidence that followed the revival of 1896. There is no sense in which the availability of the unprecedentedly buoyant supply of specialized educated manpower emerging from the Technische Hochschulen *caused* the transformation of such concerns as AEG and Siemens & Halske into giants about the turn of the century. But, allied to the even greater and arguably more decisive flow of men emerging from the middle-level technical schools (the Mittelschulen), it helped to make the transformation possible.³⁰

The German electrical industry, in fact, found itself exceedingly well supplied with the technical experts who were necessary if it was to follow the risky path of rapid expansion that commended itself, for a variety of reasons, to at least the four or five largest companies. With appropriate employees both plentiful and (because of the oversupply of graduates that became apparent, especially after 1900) cheap, opportunities for growth could be seized as they arose, and the staffing of the factories of AEG and Siemens & Halske both at home and abroad became a relatively simple matter. Also, to return to the public aura of success that it was seen as so important to sustain, it permitted ambitious forays into other, more symbolic activities, notably at the universal exhibitions in Paris in 1900 and St Louis in 1904, where the overwhelming German presence was sustained by technical support on a scale far surpassing, in size and quality, that of other European countries.

Education, research, and performance: the open questions

What survives, from all this, of the belief that certain countries were significantly helped and others impeded by the extent and

³⁰ On the often underestimated importance of the graduates of the Mittelschulen in this process, see the writings of Wolfgang König, especially "Technical education and industrial performance in Germany: a triumph of heterogeneity", in: Fox and Guagnini, *Education, Technology and Industrial Performance in Europe*, op. cit. (note 27), pp. 65-68. For a comparative discussion, which brings out the wide range of educational openings available in Germany, see Peter Lundgreen, "Engineering education in Europe and the U.S.A., 1750-1930: the rise to dominance of school culture and the engineering professions", *Annals of Science*, 47 (1990), 33-75.

character of the academic training available to their technological workforces? With regard to the earlier of our two periods, up to the early 1890s, we have argued that it would be hard to detect any correlation between, on the one hand, the pattern of take-off in electrical manufacturing and supply in different countries and, on the other, such limited variations as there were, between countries, in the availability of either theoretical knowledge or educated men. If, for example, we consider the nature of the difficulties that Thomas Edison encountered in his initial attempts to establish his European enterprise in France after the 1881 exhibition, and if we contrast those difficulties with the success he had from the moment he teamed up with Emil Rathenau to found the *Deutsche Edison Gesellschaft* (the future AEG) in Berlin in 1883, the crucial differences appear not to have been in higher education or research, where, at the time, France was scarcely, if at all, less well endowed than Germany. They lay rather in such matters as patenting policies, the availability of capital, local and national politics, and sheer commercial adventurousness.³¹

Turning to the mounting disparities in educational provision that emerged after 1890, in particular from the mid-1890s, we believe that, here too, caution is called for. By 1900, in all the countries we have discussed, the evidence was uniformly of educational systems that were highly responsive to economic conditions and capable of fashioning an ample supply of electrical engineers for whatever senior

³¹ For a comment on the difficulties facing Edison's initiatives in France see Fox, "Campaigning for Edison", *op. cit.* (note 4). The educational aspect of the comparison between France and Germany is discussed in: Peter Lundgreen, "The organization of science and technology in France: a German perspective", in: Robert Fox and George Weisz (eds.), *The organization of science and technology in France, 1808-1914* (Cambridge and Paris, 1980), pp.311-32. Lundgreen argues that the degree of similarity between the French and German systems in the late nineteenth and early twentieth centuries has been underestimated, although his figures do show how markedly Germany came to lead France in the number of engineers being produced at the highest levels of the educational system by the 1890s. In 1896, for example, there were more students in the *Technische Hochschulen* in Prussia alone than in all the technical *grandes écoles* and *écoles d'arts et métiers* throughout France (Lundgreen, *op. cit.* pp. 326-32). It should also be noted that Lundgreen's discussion does not take account of the large numbers of students in the *Mittelschulen* (see above, note 30).

technical posts were available. Indeed, the main spectre in the second of our two periods seems to have been not so much a shortage as an excess of academically qualified men. The balance was a fine one everywhere, and it is significant that, as the buoyancy of the late nineties and the boom in electrically-powered transport about 1900 gave way to the renewed depression of 1901-3, the resulting crisis of an oversupply of graduates was simultaneously apparent in Britain, France, Italy, and even Germany, where the Nuremberg firm of Schuckert, with its 8000 workers, provided a particularly spectacular illustration. Schuckert's virtual collapse upset the delicate relations between supply and demand and threw a large number of highly trained men onto an already far from buoyant job-market.³²

Of course, whatever qualitative similarities there may have been between the various national patterns in the relations between supply and demand in the provision of formally educated men, the fact remains that from the 1890s the German system of advanced technical education was both larger and better-financed than that of other European countries, and that the investment in academic laboratories and teaching facilities was sustained there in a way that no other country (with the possible exception of Switzerland) could match. But, to return to our earlier argument, it is important to see this expenditure and the high level of expertise it helped to generate as coming in the wake, rather than the vanguard, of industrial success: its contribution was to consolidate, not to initiate, Germany's lead in the European electrical industry.

On this point of timing, there is a danger of being blinded by the opulence of the German electrical laboratories in 1914 and of supposing that such a state of affairs had always existed. In reality, physics laboratories in Germany at the beginning of the age of electricity, in the 1870s, were quite as dilapidated as they were

³² The anxiety created by the fear of an oversupply in the electrical sector in France as well as Germany is reflected in the comment of the French engineer André Blondel in his paper "Que doit être l'ingénieur électricien?", in *Congrès International des Applications de l'Electricité. Marseille 1908*, (3 vols., Paris, 1909), vol. 2, pp. 564-92 (588-92).

anywhere, and initially they improved rather slowly, too slowly to provide any basis for an explanation for Germany's leap ahead in electricity.³³ In any case, far more cogent explanations are to be found in the strategies, both technological and commercial, of the great companies that embodied German success.

Even in turning to company strategy, however, there are snares, especially where technology is concerned. For it is all too tempting to assemble such signs as there were of German readiness to promote in-house research and the quest for new products and processes, and to contrast that readiness and the progressive attitudes it would seem to imply with the low level of interest in technological innovation in Britain, France, or Italy. In fact, this particular contrast does not seem to hold the key. Against the example of Siemens & Halske, who did indeed have an elaborate research laboratory from an early stage, we have to set the equally successful AEG, where there was a greater readiness to assimilate innovations from the outside, either through the work of consultants (like Walther Nernst, whose lamp was exploited by AEG) or through the acquisition of well-tried technologies which might, if necessary, be adapted or refined.³⁴ Investment in in-house research, therefore, and the academically trained staffs that went with it were the ingredients of one possible strategy for success. But a research-led policy was by no means the only one that could lead to profit. As we have argued elsewhere, even in the "slow-lane" countries, such as Britain, France, and (still more conspicuously) Italy, manufacturers were able to achieve perfectly respectable levels of profitability on the basis of technology bought in and then adjusted to local circumstances.³⁵

³³ Cahan, *An Institute for an Empire*, *op. cit.* (note 8), pp.4.

³⁴ The character of AEG's policy with regard to innovation under Emil Rathenau is commented on in Ulrich Wengenroth, "Emil Rathenau", in: Wilhelm Treue and Wolfgang König (eds.), *Berlinische Lebensbilder-Techniker* (Berlin, 1990), pp.193-209 (203, 204, and 207).

³⁵ Robert Fox and Anna Guagnini, "Life in the slow lane: research and electrical engineering in Britain, France, Italy, ca. 1900", in: Peter Kroes and Martijn Bakker (eds.), *Technological Development and Science in the Industrial age. New Perspectives on the Science-technology relationship* [Boston Studies in the Philosophy of Science, vol. 144]

Conclusion

We take this cautious view of the contribution of science and technical education to industrial performance in the knowledge that some economic historians and historians of science and technology may find its implications confusing and inelegant. For, as we have tried to show, if the distinctiveness that allowed Germany to outstrip her European rivals did not lie in the realms of high science, research, and education, the search for the roots of her success has to turn to a far less straightforward mixture of economic, social, political, and cultural circumstances, of which the contribution of scientific and educational institutions is just one part.

As our comments on AEG and on our "slow-lane" countries indicate, we believe that any analysis must include a consideration of the role of know-how of an intellectually less original kind than historians of science or even of technology normally deal with. The particular focus that this implies does not entail any marginalization of the place of technology in explaining economic success or failure. Indeed, one of the most important contributions made by the influential work of Nathan Rosenberg has been to demonstrate the great amount of knowledge that is involved in any process of technological innovation and in the transformation of technological ideas into economically profitable practices.³⁶ However, the knowledge that Rosenberg regards as so important is seldom of a kind that can easily be acquired through formal education. One corollary of this is that a major advantage of the large German electrical companies (as of their American counterparts) may have lain less in their laboratories than in their sheer size, which made them better able than their competitors to accumulate skills and to keep developing the all-important knacks that were needed for the crucial processes of adaptation and minor improvement.

Dordrecht, Boston, and London, 1992), pp.133-53.

³⁶ For a flavour of Nathan Rosenberg's writings on the subject, see his *Perspectives on Technology* (Cambridge, 1976).

Of course, most of the employees who laid the foundations for this skill-based tradition in Germany were fashioned initially in the headier world of academic engineering or physics, and they came to industry with the starry eyes of men who believed that theory, research, and the high-level training offered in institutions of higher education provided the surest starting point for technological and economic success. But the realities that awaited them in the work-place, in Germany as elsewhere, were far harsher. What might grandly be called “research” by an electrical company usually took the form of routine testing and quality control; and “development” tended to mean a long unspectacular process built of refinements and modifications of an intensely practical kind, far removed from the realm of free flights of fancy, inspiration, and Eureka moments.

The realization that, in the quest for success, the humdrum work of the industrial engineer had more scope and (despite the relentless statements about the value of science) was more prized than the creativity of the academic scientist must have bred disappointment. It entailed recognition of the fact that the “laboratory” which mattered most in the struggle for supremacy in the electrical industry before the first world war (and the chronological qualification is important) was the workshop and the site.³⁷ It was there that the small core of basic innovations (many of which, admittedly, had their origins in academic laboratories) was converted into the myriad of working practices that made the difference between technological success and failure. The rhetoric about the value of education and facilities for research that circulated ceaselessly between 1880 and 1914 had the effect of obscuring this essential fact, and it has exerted an obfuscating influence on much subsequent historical writing. It is all the more important, therefore, that we should analyse the rhetoric, carefully unravel the motivations behind it, and, above all, not confuse it with the realities of practical industrial technology, which, though obdurately less accessible than the life of science and higher education, deserve an increasing share of our attention.

³⁷ This point is explored more fully in: Fox and Guagnini, “Life in the slow lane”, *op. cit.* (note 35), pp. 139-51.