東京大学教養学部哲学・科学史部会　哲学・科学史論叢第十七号　平成 27 年 1 月 (173–199)

Rankine's Manuals and the Disciplining of 'Engineering Science' in Nineteenth-century Britain

Ruselle Meade

1. Introduction

Although British engineering had a considerable international reputation by the mid-nineteenth century, many British engineers looked enviously at the technical training institutions of their peers in France and Germany. Even by the 1870s, when the Meiji government was hiring experts such as Henry Dyer to help design the curriculum for the *Kōbu Daigakkō*, in Britain engineering had only just achieved a measure of recognition as a bona-fide academic discipline. The first efforts to introduce engineering courses, such as those in London and Durham in the 1830s and 40s, were met with apathy and failed to attract sufficient numbers of students. In light of this uninspiring track record, the success of William Macquorn Rankine's course at Glasgow has attracted much attention. Marsden (1992a, 1992b) and David Channell (1982) have described Rankine's struggles in the face of much opposition from his colleagues at Glasgow and his fellow professional engineers, and have argued that the resulting character of the discipline, which Rankine termed 'engineering science', was forged by his efforts to ensure the success of the course. Less attention has been paid to the role played by his manuals – *Applied Mechanics* (1858), *The Steam Engine and Other Prime Movers* (1859), *Civil Engineering* (1862) and *Machinery and Millwork* (1869) – in his efforts to define what constituted 'engineering science'. These manuals were a commercial success and remained a core reference for British engineers for over two generations.

Rankine's most successful work, *Civil Engineering*, was republished several times, reaching its 24th edition by 1914. So associated with 'engineering science' were Rankine's manuals that they have come to be regarded as the "prototype" of the engineering manual (Kurrer 2008:173). As James Secord has argued, textbooks are "attempts to define disciplines in particular ways," and Rankine's textbooks are no exception. Rankine wrote these textbooks as part of the process of defining the character of his discipline and delimiting its boundaries. This article thus examines how the genesis of these manuals is reflected in their content. It first explains the context that gave rise to the idea of institutionalised engineering education and then charts the establishment of this academic field before looking more closely at the technical literature that emerged to cater for this new audience. In doing so, it becomes clear that Rankine's manuals achieved their canonical status not through their inherent quality, but through their entanglement with Rankine's project at Glasgow.

2. The precarious emergence of academic engineering

The idea that the British were, in the words of one nineteenth century commentator, "an engineer-elevated people" (Mudie 1840:241) was cultivated by both engineers themselves (through, for example, autobiography) and by those who saw them as paragons of industriousness and virtue. Notable among the latter was Samuel Smiles, whose multivolume biography, *Lives of the Engineers*, sought to project engineers as role models for the general public. He tapped into the Victorian admiration for self-improvement and success through unstinting perseverance by stressing the lowly beginnings of many engineers. He presented them, not as "natural philosophers" or "mathematicians," but "men of humble station, for the most part self-educated" (Smiles 1861:xvi), who were successful because of their rare talent rather than because of exemplary training.

Meanwhile, on the continent, particularly in France, the high social prestige of engineers was linked directly to their academic training. For example, at the École Polytechnique, which counted among its staff the most prominent and esteemed mathematicians, entry was restricted to those successful in a highly competitive and academically rigorous competition that could only be passed by attending extensive preparatory courses (Lundgreen 1990:36). Looking at the French model, some engineers in Britain felt that some scientific training would not only improve their practice, but enhance their status. For example, at the inaugural session of the Institution for Civil Engineers in 1818, the engineer Henry Robinson Palmer stated:

> It is a remarkable fact that notwithstanding the extensive advancement of science and the general increase of means for an acquaintance with it, while the principles of systematic education for most of the learned and scientific professions have been and still are actively encouraged, not even an attempt seems to be made towards the formation of any special source of information or instruction for persons following or intending to follow the important profession of a Civil Engineer. (Palmer cited in Anon. 1938:138)

Support for the introduction of scientific training in engineering also came from some outside the profession, such as the natural philosopher David Brewster. Writing in the *Edinburgh Review*, he asserted: "shall we not […] insist upon a thorough and profound knowledge of civil engineering in cases where the property on the largest scale is at stake, where millions of lives are in peril, and where the highest national interests are involved?" (Brewster 1839 quoted in Marsden and Smith 2005:240).

However, the nature and extent of this scientific training was a subject for debate, and there was little appetite for it to supplant the apprenticeship model then dominant in Britain. Even in 1850, virtually the entire membership of the Society of Civil Engineers, the Institution of Civil Engineers and the Institution of Mechanical Engineers (established in 1847) had acquired their skills by working in the office of an experienced master (Buchanan 1989:162) and so there was reason for them to support the status quo. Even those, such as Isambard Kingdom Brunel, who had certainly benefited from theoretical training, held a derisory attitude toward what was considered an overly bookish approach by the French:

> I must caution you strongly against studying practical mechanics among French authors – take them for abstract science and study their statics dynamics geometry etc. to your heart's content but never even read any of their works on mechanics any more than you would search their modern authors for religious principles. A few hours spent in a blacksmiths and wheelwrights' shop will teach you more practical mechanics – read English books for practice – There is little enough to be learnt in them but you will not have to unlearn that little. (Brunel quoted in Buchanan 1989:163)

It was not that established engineers were against academic training *per se*. They likely felt that *some* such training would be beneficial, but not at the expense of the apprenticeship system, and this accounts for the rather uncoordinated introduction of courses at a number of British universities in the late 1830s and early 1840s (Marsden and Smith 2005:235). The courses offered by these institutions did not form part of a coherent degree programme; they were offered in the evenings and were thus attended mainly by journeymen (Royal Commission on Scientific Instruction 1874:20, Question 9509). Teaching these courses also held little attraction for professional engineers who could find far more lucrative employment in industry. Moreover, such courses appear to have been hampered by the lack of clarity about the extent of the scientific training to be offered, how it would benefit the engineers who had to pay for it, and to whom the courses were targeted.

Notwithstanding the lack of enthusiasm on the part of the majority of engineers or on the part of universities, Queen Victoria instituted Britain's first Regius chair in civil engineering and mechanics at the University of Glasgow in 1840, and the post was filled by the French and German-trained engineer Lewis Gordon, whose work on thermodynamics had gained him considerable renown among natural philosophers. Although the reason for crown's choice of Glasgow was not explicitly stated, Glasgow was likely chosen because of the city's industrial pre-eminence, particularly in shipbuilding. Moreover, the ancient Scottish universities had a tradition of forging strong links with industry. Regardless of the university's merits as a site of a chair in engineering, the choice took many faculty members then by surprise and they complained vociferously about this intrusion (Marsden 1998:99). The hostility of the faculty was likely due to the threat to their income posed by the addition of the chair. At this time professors' income came directly from student tuition. Not only did the introduction of the chair create more competition for students, their tuition under a Regius professor would be subsidized making it an attractive option. Faculty members therefore took the step of resisting the presence of this new chair by denying Gordon rooms for him to carry out his lectures

(Oakley 1973:5). Gordon appealed to sympathetic ears in the university hierarchy for support in getting the faculty to offer up a room for his classes. Initially this was successful but once the support ebbed away, Gordon was left isolated (Marsden 1998:107). Without students, he spent less and less time in Glasgow and eventually resigned citing the "jealousy [of] the professors of natural philosophy and mathematics" as a reason (Constable and Stevenson 1877:227).

3. The introduction of Rankine's 'engineering science'

From Gordon's experience it was clear that his successor would require a high degree of political nous to carve out a position for engineering within the academy. It would be necessary to placate two main constituencies. There were those established engineers who felt that such courses were unnecessary. Then there were those in the faculty who saw the engineering course as an intrusion and whose campaign to oust Gordon had been successful. In addition, there were the students themselves. They would need to be presented with a compelling reason why they would be better off taking an academic course in engineering. When Rankine was appointed as professor in 1855 his first task was to demonstrate his expository ability by presenting a thesis in Latin to the Senate (Henderson 1932:9). Drawing on a rich history of similar rhetoric within the engineering profession, Rankine entitled it "The Harmony between Theory and Practice in Mechanics." However, whereas Gordon had used the theoretically-oriented polytechnic schools of engineering on the continent as a model (Constable and Stevenson 1877:227), Rankine sought to avoid encroaching on the territory of the natural philosophers in his faculty. He claimed that the new discipline would instead be concerned only with those branches of science for which there was practical application. To engineers, he appealed for a rapprochement with natural philosophy, suggesting it would benefit them by enabling them to achieve those core Victorian aims of efficiency and economy. For Rankine, the lack of efficiency within the profession was particularly unfortunate.

When Rankine presented his agenda for engineering he sought to define its unifying ethos as the pursuit of perfection (Marsden and Smith 2005:250). Science, he observed, had "[effected] more in a few years than mere empirical progress had done in nineteen centuries" (Rankine quoted in Marsden and Smith 2005:237). As Daston and Galison (1992:83) have suggested, science was a means of grounding the activity of artisans in the nineteenth century in objective science that privileged the "plodding reliability of the bourgeois" over the "genius" of an art where the secrets of the trade were passed from master to apprentice on the shop floor. Rankine felt engineering achievement should be grounded in numbers, that it should be quantifiable (Marsden and Smith 2005:250). His vision centred on a mission to base engineering practice on mathematically-based computation, which would ensure precision and a high degree of efficiency in practice (Marsden 1992a:330).

Rankine also appealed directly to engineers, urging them to see how incorporating scientific training in engineering worked for the greater good: "the cultivation of the Harmony between Theory and Practice in Mechanics – of the application of Science to the Mechanical Arts (…) [promotes] the comfort and prosperity of individuals, and augments the wealth and power of the nation" (Rankine 1877:10). Moreover, he implied, it had a morally transformative effect: "the commonest objects are by science rendered precious; and in like manner the engineer or the mechanic, who plans and works with understanding the natural laws that regulate the results of his operations, rises to the dignity of a Sage" (*ibid.*:11).

Rankine knew it was important to signal his commitment to the apprenticeship model to keep both newcomers as well as established engineers on side. He was an advocate of the art of engineering and lamented that practical skill had been "regarded as accomplishments of an inferior order, to which the philosopher (…) condescended" (Rankine 1877:2). He made sure to underscore that, having himself been socialised into the discipline via an apprenticeship, he did not intend for this academic discipline to supplant the apprenticeship system. Considering the lukewarm reception of academic engineering courses by the Institution of Civil Engineers and the lack of immediate practical benefit to engineers it would, in any case, have been foolhardy to suggest a complete transition to university based system. What Rankine envisaged was a course that would provide students with a theoretical foundation from which they could improve their practice:

> In drawing up that course the University have had in view to avoid altogether any competition with the offices of civil engineers, or the workshops of mechanical engineers, or any interference with the usual practice of pupilage or apprenticeship; and they have accordingly adopted a system which is capable of working in harmony with that of pupliage or apprenticeship, by supplying the student with that scientific knowledge which he cannot well acquire in an office or workshop, and avoiding any pretension to give him that skill in the conduct of actual business which is to be gained by practice alone. (Rankine quoted in Royal Commission on Scientific Instruction 1874)

The course thus developed included training in mathematics, natural philosophy, geology and mineralogy. About one third of the course was devoted to civil engineering and mechanics (University of Glasgow 1870:40). Also, true to his word, Rankine encouraged his students to supplement their training by working as apprentices. Students on his course were explicitly advised to spend "two or three summers" during their course at university "in offices, or in workshops, or in works such as railways, water works, or harbour works, in progress" (*ibid.*:55).

As Marsden (1992a, 1992b) has pointed out, the ingenuity of Rankine's approach lay in his skilful rhetoric. He had cordoned off academic territory by not simply appealing for the incorporation of pure science into engineering practice. By coining the name 'engineering science' he wanted to ensure that this new field did not occupy a subordinate position to science. Pure science was not merely being appropriated and applied. Scientific principles were being used to guide the practice of engineering. This subtle difference in presentation suggested that engineering science was a distinct and independent species of science. It was therefore homologous to the other branches of natural philosophy, which represented an "autonomous [body] of teachable knowledge" that required its own curriculum (Kline 1995:197).

It was a system that succeeded because it also mastered the art of compromise. Tait, Rankine's contemporary, thought that Rankine's course had endured because of his "clear discrimination of what is permanent and can be taught, from that which must vary from day to day, and can only be acquired by personal experience; the distinction between the science and the art of the engineer" (Tait 1881:xxxv). It is apparent that his message found an audience, and not just in Glasgow. Students came from further afield in Scotland, and also from London, Birmingham and Manchester. Some appear to have travelled from even further. The course calendar for 1870 notes that a Lewis Rogers Kean from Louisville, Kentucky had been awarded the Certificate of Proficiency in Engineering Sciences, and that a George Flower from Cape Town, South Africa was currently enrolled (University of Glasgow 1870).

Soon the status of engineering as an academic discipline seemed to be settled. By 1870 the Secretary of State for India had assured that attending the course at Glasgow for at least two years "would qualify a student (…) to compete for admission" to the engineering colleges run by the British colonial government in India (University of Glasgow 1870). Rankine's campaign to make engineering science a degree, rather than certificate, level course came to fruition shortly after his death. Similar courses started appearing elsewhere, notably, in Manchester, Belfast and London (Marsden 1992a, 1992b). The description of Osborne Reynolds' course at Owen's College, Manchester (see Owens College 1869), looked almost identical to Rankine's at Glasgow. According to McKitterick (2009:528) Rankine also served as a model for James Ewing, professor of mechanism and applied mechanics at the University of Cambridge. In his inaugural lecture at Cambridge, Ewing (1891:15) stated, "I have to plead for nothing less than the inclusion of a complete School of Engineering in that new Cambridge which is fast springing up within the old." He asserted to his audience at Cambridge, one of the last bastions of resistance to 'engineering' (as distinct from 'applied mechanics'), "the question is not whether a school of engineering is a legitimate part of a university, but whether a university is reasonably complete without a school of engineering" (*ibid.*:18).

4. Rankine's textbooks and the disciplining of engineering

Key to the success of engineering within the academy was Rankine's series of manuals, which he deployed effectively to gain acceptance for his particular representation of engineering. They were a tremendous success, and all saw several editions; there were 21 editions of *A Manual of Applied Mechanics* and even this was exceeded by *A Manual of Civil Engineering*, which had reached its 24th edition by 1914 (Kurrer 2008:173). They were widely used as textbooks, and were made required reading for some of the new engineering programmes that were beginning to appear, as attested to in calendars for Owen's College and University College London. They were also translated into several languages (*ibid*). The works also found renown among Rankine's peers. Gordon, Rankine's predecessor at Glasgow, described the manuals as 'the permanent *Principia* of Engineering', a treatise that was to the engineering sciences what Newton's *Principia* was to physical sciences (Marsden and Smith 2005:242). Notwithstanding his self-interest, a former editor at Charles Griffin and Company Ltd., the publishers of Rankine's works, claimed:

> (…) to the genius of Rankine, the engineering world owes a debt which can never be repaid. Rankine's four manuals […] are classics. It is hardly an exaggeration to say that nearly all the engineering textbooks which have appeared in the last half-century have to a great extent been modelled upon the lines laid down by Rankine, and are based upon principles which he first enunciated. (Beare 1920:102)

There might be a whiff of hyperbole in these claims but there is sufficient evidence to substantiate them. However, Rankine's manuals were not successful on account of their perfection. The textbooks, all of which exceeded 500 pages, did not make easy reading. There were complaints about their volume and intricacy; Rankine's style, it was said, presumed "no scarcity of printers or of paper" and had been written for "readers without our modern craving for compression [or] readiness for occasional relaxation" (Southwell 1956:180). Timoshenko (1953:44), too, found that Rankine's books were "difficult to read," while T. Hudson Beare, Regius Professor of Engineering at the University of Edinburgh and an admirer of Rankine, admitted that although the manuals "appeal to a wide circle of readers and students, there was a still more numerous band of students for whom Rankine's work was too strong meat" (1920:105). Despite these criticisms, Rankine sold well. This is because he was able to harness these manuals as tools of discipline. That is, he was able to mobilise them as a means of staking out the contours of the field. He did so by making them a tangible embodiment of 'engineering science'. He also needed to make them successful, and he achieved this through his considerable efforts at networking. To understand these accomplishments, it is necessary to first provide some context by exploring the technical literary field in Britain during the mid-nineteenth century.

Rankine's works were by no means the only manuals in circulation when they were published. Works by continental authors were popular and among the references that pepper Lewis Gordon's lecture notes are texts such as *Leçons de la Méchanique* by Navier, *Méchanique Industrielle* by Poncelet, *Rapports sur les Chemins de Fer* by Teisserenc and *Cours de Construction* by Sganzin, in French; *Carte idrauliche della Valle di Chiana* in Italian; and *Droogmaking van de Haarlemmer Meer* by van Lynden in Dutch. Works in German were also frequently referenced. There were not only foreign texts. In his lecture notes, Rankine cites Bulter Williams' *Practical Geodesy*, Fairbairn's *Useful Information* *for Engineers*, Tredgold's *Principles of Carpentry*, and many others. There were also translations, such as *Principles of the Mechanics of Machinery and Engineering* by Julius Weisbach, the translation of which saw Gordon's involvement. It is not clear whether Gordon recommended that his students use this rather comprehensive textbook (although at two volumes and a price of £1.19s, it was hardly affordable). Hippolyte Bailliere, the publishers of this work, had a 'Library of Illustrated Standard Scientific Works', which included other translations from German, such as *Technology, or Chemistry Applied to the Arts and to Manufacturers* by Friedrich Knapp, and *Principles of Physics and Meteorology* by Johann Muller, which would have been of interest to engineers.

Speaking of the nineteenth century, Secord (2009:467) noted, "in a period when the very definition of science was controversial, [textbooks] were not the routine, mechanical summaries of known facts they are often taken to be, but *attempts to define disciplines in particular ways*" (emphasis added). He gives a range of examples that played an important role in creation of academic disciplines, from James Clerk Maxwell's *Treatise on Electricity and Magnetism* in 1873, to Michael Foster's *Textbook of Physiology* (1870) and Archibald Geikie's *Text-book of Geology* (1882). Textbooks were able to achieve this disciplining role because authors could use them as a means of "promoting the practices and conventions" that could bind their disciplinary communities (Secord 2009:505).

The success of such works could be multiplied by being aligned with an institutionalised discipline, and the proliferation of new courses in science at universities in this period "created an unprecedented market for scientific and technical works" (Secord 2009:468). The growth of education and rise of publishing meant that textbooks could become commercial successes. Robert Potts's *Euclid's Elements of Geometry* (1845) is one such example. The success of this work was "immediately colossal and international" (McKetterick 2009:358). It sold almost twenty thousand copies within a few years. Its publisher, Parker, realising the market available, took out numerous advertisements in various genres to promote the work further increasing its sales (*ibid.*).

Such possibilities for success meant that professors were increasingly expected to publish textbooks. An Oxford University Commission noted that in previous years lectures were published because of the unavailability of suitable manuals, but that professors were now in the position to "[furnish] the student with a chart to guide him through the labyrinth of knowledge that surrounds him" (Oxford University Commission 1852:xxii, cited in McKetterick 2009:501). Earlier technical barriers to the typesetting of mathematical formulae had also now been overcome (Secord 2009:466). This meant that companies such Charles Griffin and Company Ltd., the publishers of Rankine's work, could capitalise on these developments to specialise in this market. The publishing company noted that in excess of ninety per cent of their publications were "technical and scientific textbooks, manuals, and monographs" (Griffin, Charles, and Company, ltd. 1920:8).

As previously discussed, Rankine encountered resistance to 'engineering science' from many quarters, and attempted – through his speeches to the Senate and witness statements at the Royal Commission on Scientific Instruction – to delineate an academic space for the discipline. It is evident from the character of his manuals that he intended them to be used as 'tools' for the benefit of this campaign. He could achieve this by making them a tangible and mobile embodiment of 'engineering science'. He sought to achieve this through exhaustiveness, and to imbue the field with mathematical rigour.

Perusal of the tables of contents of the manuals renders evident Rankine's desire to inscribe all that constituted knowledge within the discipline or, as

Kurrer (2008:176) puts it, to present "the whole gamut of civil engineering knowledge." One might expect there to be a trade-off between exactitude and exhaustiveness. However, Rankine, it seems, was not troubled about reconciling these competing ambitions. Although a vast range of material is covered in his manuals, there is no concomitant tendency to skim over detail, which is the likely reason he created a series rather than a single-volume manual. In aiming to present an all-encompassing and systematically organised compilation of engineering knowledge he is heir to the tradition established by the Encyclopaedists, who through their enterprise to catalogue all that was known of the world created branches of knowledge that later constituted the various 'sciences', bodies of knowledge centred on a particular method or object of inquiry. As Kurrer (2008:177) notes, many of the branches of engineering that developed later in the nineteenth and early twentieth centuries did so in accordance with the divisions Rankine established in his manuals.

Rankine's encyclopaedic ambitions are evident from the structure he adopts in presenting each of his manuals. They are first divided into 'parts', which are then further broken into 'sections', then 'chapters' and, finally, entries. For example, *A Manual of Civil Engineering* is comprised of three major parts: 'Engineering Geodesy', 'Materials and Structures', and 'Of Combined Structures', as is *A Manual of the Steam Engine*, which comprises: 'Muscular Power', 'Water Power and Wind Power', and 'Steam and other Heat Engines'. These are then each broken down into six or seven chapters each, which then are further broken down by 'section', which are then further divided into entries (for example, in the case of 'Timber' the entries include 'shafts and pits', 'tunnels in dry and solid rock', 'tunnels in dry fissured rock', 'tunnels in mud' and so on. There are 528 of these individual entries, almost as many as there are pages. This modular structure recurs in all of his manuals. In this way, readers could simply drill down to the entry pertaining to the knowledge they sought.

Another key characteristic of Rankine's Manuals is his extensive use of mathematical modelling to represent natural phenomena. Rankine equated 'science' with 'truth'. In this respect his attitude echoes his education in natural philosophy under James David Forbes at the University of Edinburgh. At this time there was a growing belief in Britain in the innate superiority of "a rationality based on precision measurements ordered in algebraic equations and algebraic language" (Wise 1995:97). As discussed, in France algebra and calculus-based pedagogy had long been established at the *École Polytechnique* (Picon 1992) but in Britain where the apprenticeship model prevailed, many were less convinced of its necessity and objected to algebra on the grounds that it replaced the thinking and judgement of the forcing resulting in a reasoning abstracted from a tangible and immediate material reality. Therefore, although Rankine's moves to make engineering more mathematical were in line with wider societal currents, they did, to some extent, run against the grain of actual engineering practice.

Rankine's quantitative modelling of natural phenomena and reference to physical laws to explain engineering practice represented his desire to move engineering practice away from the inconsistency of empiricism to the rigor of method. This is evident in his prescription of the ideal means of advancing knowledge:

> An essential distinction exists between two stages in the process of advancing our knowledge of the laws of physical phenomena; the first stage consists in observing the relations of phenomena, whether of such as occur in the ordinary course of nature, or of such as are artificially produced in experimental investigations, and in expressing the relations so observed

> by propositions called formal laws. The second stage consists in reducing the formal laws of an entire class of phenomena to the form of a science (…). Such a system of principles, with its consequences methodologically deduced, constitutes the physical theory of class of phenomena. (Rankine 1855:209)

This approach can also be seen in Rankine's activities leading into his publishing. During his inaugural address to the Institution of Engineers in Scotland, of which more will be said shortly, he noted that there was a wealth of knowledge about the strength of materials that engineers had acquired experientially, either through the intentional testing or "incidentally in the course of practice" Rankine (Institution of Civil Engineers in Scotland 1857:5), and appealed to members to report such findings so that they could be disseminated. The notes on which his manuals were based show that he did rely on such reports that assembled a critical mass of experiential information to identify patterns that would allow predictions of the behaviour of materials. These then made their way into his textbooks.

Some within the profession looked at this emphasis on mathematics favourably, citing it as having brought prestige to the image of engineering. Cook (1951:271, cited in Southwell 1956:189), who followed in Rankine's footsteps to become Regius professor of civil engineering and mechanics at the University of Glasgow, as well as president of the Institution of Civil Engineers and Shipbuilders in Scotland, stated of Rankine, "he is acknowledged as one of the great pioneers in the movement to bring the powerful resources of mathematics and physical science to the practical problems of the engineer," adding that Rankine was "an exponent of unusual power of the ideas and principles which constitute the framework round which engineering science is built." However, many of his contemporaries had reservations. Trautwine, for example, viewed Rankine's modelling as a form of mathematical sophistry, complaining that "the most simple facts [had been] buried out of sight under a heap of mathematical rubbish" (Trautwine 1872:viii). His biographer Tait more sympathetically remarked that his mathematical modelling had, on occasion, been "quite unnecessary" (Tait 1881:xxvi). The fact that Rankine's works attracted this kind of criticism from his peers underscores that his approach of incorporating mathematics in engineering was indeed unprecedented at this time. Moreover, it indicates that this development did not meet universal approval. Rankine would therefore need to convince others of the merits of his approach.

5. Rankine's networking

Rankine could not ensure the success of his works simply by inscribing them. A great deal of work is required to ensure that texts are read, not to speak of them finding a wide audience. This was something of which Rankine was aware and he used connections to raise his profile. Rankine was as prolific a networker as he was a writer. He became inaugural president of the Institution of Civil Engineers in Scotland when it was founded in 1857. This group had frequent meetings – about eight per annual session according to its General Minutes for the first year – and during each of these meetings papers were presented on "various subjects connected to the objects of the Institution." These were then "followed by a discussion on the subject of which it treated" (Institution of Civil Engineers in Scotland 1857). Many of these topics were of particular interest to Rankine, and were discussed in his manuals. For example, there were papers or notes on a "joint-chair recently adopted on a portion of the Glasgow and South-Western Railway," "American locomotive engines," and a "description of a centrifugal pump," as well as discussions on whether the French metric system should be adopted, and so on (*ibid*.).

Rankine cultivated strong links with industry and industrialists through the Institution. According to the General Minute book of its first year, the inaugural vice presidents included such prominent Glaswegian industrialists as James R. Napier, Walter Neilson and William Tait. Also members of the Institution, which initially only numbered sixteen, were the entrepreneur John Elder and coal magnate William S. Dixon. Membership in this group therefore inserted Rankine firmly at the heart of Glaswegian industrial elite and, crucially, provided him with links into the world of publishing.

Rankine's associations with some members of the group preceded the formation of the Institution. For example, John Elder was a business partner of Rankine. The two had worked together to create a two-cylinder compound, which was intended to improve the efficiency of marine engines. Rankine's expertise in thermodynamics (much of which was developed through this collaboration, and which appeared in his *Manual of the Steam Engine and Other Prime Movers*) proved decisive, and following successful experimentation, Rankine and Elder took out a patent for their engine in 1853 (Moss 2004). Elder's wife, Isabella, was also an important associate. She was a noted patron of education in general, and women's education in particular. On John Elder's death in 1872 she bequeathed £5,000 to increase the salary of the Regius professorship in civil engineering and mechanics (University of Glasgow 1880:50).

Other important links to industry were cultivated through acquaintances with others, including William S. Dixon. Dixon was part of a family that had, for three generations, been successful coal miners, and about the time of the establishment of the Institution he was expanding his business in the

Glasgow area. Walter Neilson, for his part, was a key player in the Glaswegian locomotive industry, and is said to have been "largely responsible for creating Glasgow's worldwide reputation for steam locomotive production" (Mayor 2009).

Rankine's associates in the Institution provided him with links not only to industry, but also to the publishing world. Charles Griffin and Company were the publishers to the University of Glasgow and so they would have been the most obvious house to publish Rankine's works. However, the presence of others in the Institution with links to publishing put Rankine in the company of those who were at ease in the publishing industry. Among the members of the Institution was James R. Napier, who was an author as well as a library proprietor. Napier's had become involved in publishing when one of his essays on dyeing was published by James Griffin. This led to further work within the company and Napier eventually became involved in the firm to develop the use of electrotype for publishing, particularly illustrated works. At about the same time as the establishment of the Institute, he had become active in both the writing and technical aspects of publishing, writing a scientific manual series for Griffin (McConnell 2004). Although the minutes of the Institution make no reference to discussions on publishing, it is implausible that he did not discuss his manuals with his associates there as their discussions were so closely linked to the material Rankine was publishing.

More recent re-assessments of Rankine's accomplishments have suggested that during his lifetime Rankine was actually a more marginal figure in both the engineering and scientific communities than his posthumous canonisation would suggest. He was regarded ambivalently by the scientific community who remained unconvinced by the originality of his contributions, and many of his grand infrastructure plans, were accomplished by other more seemingly competent and business-minded engineers (Marsden 2013). Paradoxically, it appears that 'engineering science' at Glasgow became his legacy because of his failure to leave the legacy he desired as both a scientist and an engineer.

6. Conclusion

Rankine's success at Glasgow and his networking activities enabled him to reach wide audiences. He was able to propagate his vision of the field by, firstly, making the texts an embodiment of his vision of 'engineering science': he had set out the contours of the field – its encyclopaedic scope suggested that what had been included in the manuals existed within the field and those not covered were not part of it. Secondly, his vision of 'engineering science' as a 'harmony of theory and practice' can be seen in his application of mathematics, which lent an air of rigour to his work. Finally, he used his network of connections to raise his profile and to disseminate his work. A key component of his success was, however, his base in Glasgow. His course at the university first needed to be successful for his manuals to have an audience. The University calendar for the years 1863-64 show thirteen students on Rankine's course. By 1865, the number had surpassed twenty, and that number had doubled five years later. There were efforts to widen the student body on the course. For example, there were the Metcalfe Bursaries "for encouraging poor students in prosecuting the studies of Mathematics, Practical Astronomy, Chemistry, and Civil Engineering" as well as a generous Fellowship of £100 and a bursary of £25 to bring new students to the course (University of Glasgow 1870). As mentioned, students came from far and wide and this helped perpetuate Rankine's vision of the discipline. One of his successors in the Regius professorship, Archibald Barr, came from this student body. Barr, an exemplary student who had won several prizes as a student under Rankine, was appointed 'Young assistant' to James Thompson, Rankine's immediate successor, before succeeding him in 1889. When Itō Hirobumi went looking for someone to help develop engineering education in Japan, Rankine's success at Glasgow made him an obvious person to consult about the choice, and he suggested one of his protégés, Henry Dyer, for the task. A few years after Rankine's death, two of his works (*Civil Engineering* and *Prime Movers*) were translated into Japanese. Going against the grain of translation practice during the period, whereby books were invariably abridged and reformulated, utmost care was taken not to tamper with Rankine's opus. All sentences, including the punctuation, are kept intact. There is no difference in the illustrations. Even references to English works that have no Japanese translation are kept as they were in the original. The profound reverence shown to Rankine's work is testament to its canonical status in engineering.

References

Anon. (1938) 'Proceedings of Scientific Societies', *The Civil Engineer and Architect's Journal* 1: 138-145.

Beare, Hudson (1920) 'Engineering', in Griffin, Charles and Company, ltd. (eds) *The Centenary Volume of Charles Griffin and Company Ltd, Publishers, 1820-1920*, London: C. Griffin and Company.

Birse, Ronald M. (1983) *Engineering at Edinburgh University: A Short History*. Edinburgh: University of Edinburgh, School of Engineering.

Brewster, David (1939) 'Review of The Life and Works of Thomas Telford', *The Edinburgh Review* 70: 1-47.

Buchanan, R. Angus (1983) 'Gentlemen Engineers: The Making of a Profession', *Victorian Studies* 26 (4): 407-429.

Buchanan, R. Angus (1985) 'The Rise of Scientific Engineering in Britain', *British Journal of the History of Science* 18 (2): 218-233.

Buchanan, R. Angus (1989) *The Engineers: A History of the Engineering Profession in Britain, 1750-1914*, London: Jessica Kingsley.

Buchanan, R. Angus (2011) Brunel, Isambard Kingdom (1806–1859), in *Oxford Dictionary of National Biography*, Oxford University Press. Available online at http://www.oxforddnb.com/view/article/3773 (accessed 18 Feb 2013).

Cambridge University Commission (eds) (1852) *Report of Her Majesty's Commissioners Appointed to Inquire into the State, Discipline, Studies, and Revenues of the University and Colleges of Cambridge*, London: W. Clowes and Sons.

Channell, David F. (1982) 'The Harmony of Theory and Practice: The Engineering Science of W.J.M. Rankine', *Technology and Culture* 23 (1): 39-52.

Constable, Thomas and David Stevenson (1877) *Memoir of Lewis D. B. Gordon, F.R.S.E., Late Regius Professor of Civil Engineering and Mechanics in the University of Glasgow*, Edinburgh: T. and A. Constable.

Cook, Gibert (1951) 'Rankine and the Theory of Earth Pressure', *Geotechnique* 2 (4): 271-279.

Daston, Lorraine, and Peter Galison (1992) 'The Image of Objectivity', *Representations* 40: 81-128.

Gibb, Alexander (1935) *The Story of Telford: The Rise of Civil Engineering*, London: Alexander Maclehose.

Great Britain Royal Commission on Scientific Instruction and the Advancement of Science (1874) *Scientific Instruction and the Advancement of Science. Minutes of Evidence, Appendices, and Analyses of Evidence, Vol. II.*, London: H.M. Stationery Office.

Griffin, Charles and Company, ltd. (1920) *The Centenary Volume of Charles Griffin and Company Ltd, Publishers, 1820-1920*, London: C. Griffin and Company.

Henderson, James Blacklock (1932) *Macquorn Rankine: Professor of Civil Engineering and Mechanics in the University of Glasgow, 1855 to 1872, an Oration*, Glasgow: Jackson, Wylie and Co.

Herschel, John (1867) *Familiar Lectures on Scientific Subjects*, London: D. Strahan.

Hilken, Thomas J. N. (1967) *Engineering at Cambridge University: 1783-1965*, Cambridge: Cambridge University Press.

Institution of Civil Engineers in Scotland (ed.) (1857) *General Minutes 1857-58*, Glasgow: Institution of Civil Engineers in Scotland.

Kline, Ronald (1995) 'Construing "Technology" as "Applied Science": Public Rhetoric of Scientists and Engineers in the United States, 1880-1945', *Isis* 86: 194-221.

Kurrer, Karl-Eugen (2008) *The History of the Theory of Structures: From Arch Analysis to Computational Mechanics*, Berlin: Ernst & Sohn.

Lundgreen, Peter (1990) '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 (1): 33-75.

Lundgren, Anders and Bernadette Bensaude-Vincent (eds) (1999) *Communicating Chemistry: Textbooks and their Audiences, 1789-1939*, Canton, Massachusetts: Science History Publications.

Marsden, Ben (1992a) 'Engineering Science in Glasgow: Economy, Efficiency and Measurement as Prime Movers in the Differentiation of an Academic Discipline', *British Journal for the History of Science* 25 (4): 319-46.

Marsden, Ben (1992b) 'Engineering Science in Glasgow: W.J.M. Rankine and the Motive Power of Air', unpublished doctoral thesis, University of Kent at Canterbury.

Marsden, Ben (1998) "A Most Important Trespass': Lewis Gordon and the Glasgow Chair of Civil Engineering and Mechanics, 1840-55', in Crosbie Smith and Jon Agar (eds) *Making Space for Science*, London: Macmillan.

Marsden, Ben (2013) 'Ranking Rankine: W.J.M. Rankine (1820-72) and the Making of 'Engineering Science' Revisited', *History of Science* 51 (4): 434-56.

Marsden, Ben, and Crosbie Smith (eds) (2005) *Engineering Empires: A Cultural History of Technology in Nineteenth-Century Britain*, Basingstoke and New York: Palgrave Macmillan.

Mavor, John (2009) 'Neilson, Walter Montgomerie (1819–1889)', in *Oxford Dictionary of National Biography*, Oxford University Press. Available online at http://www.oxforddnb.com/view/article/98140 (accessed 18 Feb 2013).

McConnell, Anita (2004) 'Napier, James (1810–1884)', in *Oxford Dictionary of National Biography*, Oxford University Press. Available online at http://www.oxforddnb.com/view/article/19757 (accessed 18 Feb 2013).

McKitterick, David (2009) 'Publishing for Trades and Professions', in David McKitterick (ed.) *The Cambridge History of the Book in Britain, Volume VI, 1830-1914*, Cambridge: Cambridge University Press.

Mudie, Robert (1840) 'The Institution of Civil Engineers', *Surveyor, Engineer and Architect* 1 (11): 241-244.

Oakley, Charles Allen (1973) *A History of a Faculty: Engineering at Glasgow University*, Glasgow: University of Glasgow, Faculty of Engineering Jubilee

Committee.

Owen's College (1870-1880) *Owen's College Calendar*, Manchester: Owen's College.

Oxford University Commission (1852) *Report and Evidence, Parliamentary Papers*, London: W. Clowes and Sons.

Paxton, Roland (2008) 'Telford, Thomas (1757–1834)', in *Oxford Dictionary of National Biography*, Oxford University Press. Available online at http://www.oxforddnb.com/view/article/27107 (accessed 18 Feb 2013).

Picon, Antoine (1992) *French Architects and Engineers in the Age of Enlightenment*, Cambridge: Cambridge University Press.

Rankine, William John Macquorn (1855) 'Oultine of the Science of Energetics', *Proceedings of the Philosophical Society of Glasgow*.

Rankine, William John Macquorn (1858) *A Manual of Applied Mechanics*, London: Charles Griffin & Company.

Rankine, William John Macquorn (1859) *A Manual of the Steam Engine and other Prime Movers*, London: Charles Griffin & Company.

Rankine, William John Macquorn (1862) *A Manual of Civil Engineering*, London: Charles Griffin & Company.

Rankine, William John Macquorn (1869) *A Manual of Machinery and Millwork*, London: Charles Griffin & Company.

Rankine, William John Macquorn (1877) 'Preliminary Dissertation on the Harmony of Theory and Practice in Mechanics', in William John Macquorn Rankine (ed.) *A Manual of Applied Mechanics*, London: Charles Griffin & Company.

Smiles, Samuel (1861) *Lives of the Engineers with an Account of their Principal Works: Comprising also a History of Inland Communication in Britain*, London: John Murray.

Smith, Crosbie and Jon Agar (eds) (1998) *Making Space for Science*, London: Macmillan.

Southwell, Richard V. (1956) 'W.J.M. Rankine: A Commemorative Lecture, delivered on 12 December, 1955, in Glasgow', *Proceedings of the Institution of Civil Engineers* 5 (3): 177-193.

Tait, Peter G. (1881) 'A Memoir of the Author' in William J. M. Rankine (ed.) *Miscellaneous Scientific Papers of W.J. Macquorn Rankine*, London: Charles Griffin and Company.

Timoshenko, Stephen P. (1953) *History of Strength of Materials: With a Brief Account of the History of Theory and Elasticity and Theory of Structures*, New York: McGraw-Hill.

Trautwine, John C. (1872) 'Preface to the 1st edition', in John Trautwine (ed.) *Civil Engineer's Pocket-Book*, Philadelphia: John Wiley & Sons.

University College London (1875-1880) *University of London University Calendar*, London: University College London.

University of Glasgow (1858-1880) *University of Glasgow University Calendar*, Glasgow: University of Glasgow.

Watson, Garth (1988) *The Civils: The Story of the Institution of Civil Engineers*, London: Thomas Telford.

Wilson, George M. (1998) 'Plots and Motives in Japan's Meiji Restoration', in Peter F. Kornicki (ed.) *Meiji Japan: Political, Economic and Social History 1868-1912*, London and New York: Routledge.

Wise, M. Norton (1995) *The Values of Precision*, Princeton: Princeton University Press.