Pioneering Education for a Unique Engineering Profession – British Military Engineers

Nicholas A. Bill
St Peter's College, University of Oxford, UK

Introduction

Whilst much has been written about the early history of the civil engineering profession and its systems of education, comparatively little has been said regarding military engineers. The trajectory of their profession, influenced largely by their pioneering systems of education, saw military engineers play a crucial role in the development of science, engineering, and construction practices across the British Empire.

British military engineers were extensively involved in building and engineering projects throughout the nineteenth century and operated at the vanguard of imperial expansion. During peacetime, successive governments, both at home and in the colonies, used their expertise in science and engineering to further economic and technological development within their respective territories. Amongst their numerous responsibilities, military engineers were charged with developing infrastructure that helped establish new colonies, often years before civilian engineers and architects arrived.

Most territories fell under the domain of the Royal Engineers. Established in 1717 under the control of the Board of Ordnance, the Royal Engineers were responsible for providing scientific and engineering support to the British Army. Together with the Royal Artillery, they became known as the "Scientific Corps" and were a vital instrument to the Board of Trade. They served on numerous royal commissions and advised Parliament on issues concerning infrastructure projects. Moreover, they facilitated direct governmental intervention in the business of railways, providing an exclusive source of inspecting officers for Her Majesty's Railway Inspectorate until the 1960s.

Prior to 1862, British India remained under the control of the East India Company, which fielded three essentially private armies to defend the Company's interests and control the Presidencies (Bengal, Bombay and Madras), each possessing their own corps of engineers. These were used extensively in public works and have left behind a rich architectural legacy ranging from railways stations to cathedrals. Despite their separation, officers in British India maintained close contact with the Royal Engineers, collaborating on several projects before they were ultimately absorbed into the latter when the Crown asserted direct control.

British military engineers could rise to these challenges owing largely to their innovative and pioneering system of education. Whilst their civilian counterparts embarked upon a haphazard system of unregulated apprenticeships, military engineers enjoyed a more structured and systematic approach to their education, which was provided by some of Britain's finest scientific minds. Subject to continual reforms, it was designed to equip officers with the necessary skills to operate effectively in isolated colonial outposts. Furthermore, their continued professional development was supported through their own series of publications and the establishment of libraries at key strategic locations around the empire.

This paper focuses on the pioneering education of British military engineers at Woolwich, Addiscombe and Chatham, during the late-eighteenth and early-nineteenth centuries, particularly their training in design and building construction. Drawing comparisons with civilian engineers, it will demonstrate how they developed an institutional locus, furthering engineering science.

Royal Military Academy, Woolwich

Attempts to formalise military education began with the foundation of the Royal Military Academy, Woolwich, in 1741. Affectionately labelled "The Shop", owing to the use of converted workshops at the Royal Arsenal, the academy was the first military and technical school in the British Empire [1]. As stated in its Royal Warrant, its purpose was to educate cadets "In the several parts of mathematics necessary to qualify them for the service of the artillery and the business of engineers [2]." Essentially the principles of gunnery and fortifications. Intrinsically linked, prospective officers for both the Royal Artillery and Royal Engineers initially received the same training before being allocated into each service based upon their final examination scores, with those scoring the highest marks commissioned into the Royal Engineers.

Recruitment and Admission – Tentative Steps towards Meritocracy

Until 1855, nomination for a cadetship was at the sole discretion of the Master-General of the Ordnance [3]. Despite this system of patronage, cadets were still required to pass an examination before receiving their commission, the first branch of the British Army to impose such a requirement. In contrast, officers entering regiments of the line received their commissions via a system of purchase, rather than meritocratic award. Coupled with relatively low pay, this represented a significant and intentional financial barrier to entry. Moreover, prior to the establishment of Royal Military College at Great Marlow and High Wycombe, some 60 years later, infantry and cavalry officers were not required to undertake formal military training [4].

The system of patronage still required cadets to possess sufficient social connections. Consequently, cadets reflected the general pattern of army officers with respect to their social origins, although not usually the most affluent. Cadets came from all corners of the United Kingdom and the colonies. However, the Scots were over-represented by proportion of their population. Prior to 1855, many came from military families or those in the civil service, with almost all educated at notable schools or under private tuition [5]. Every cadet was literate and arrived with some knowledge of mathematics and the French language, as reflected in the content of the entrance examination [6].

Entry into the civil engineering profession presented similar financial and social barriers. Other than those who were entirely self-taught, young men wishing to receive instruction from established civil engineers, were typically required to pay a premium towards their education, in a system of unregulated apprenticeships known as pupillages [7]. No formal examinations were required, either at the beginning or end of their training, other than the exam necessary to obtain membership of the professional institutions. Hence, the quality of instruction varied significantly.

After 1855, following the dissolution of the Board of Ordnance, nominations were replaced entirely by open competitive entrance exams, with the intention of widening access and attracting the best candidates [8]. This ended the days of boys as young as 14 being admitted on the basis of family privilege, with the age limit raised, the mid-nineteenth century saw a new generation enter Woolwich, including university graduates [9].

Professors and Tutors

Despite its military function, most professors and tutors at Woolwich were civilians, except for those conducting classes focused on practical gunnery or other aspects related to soldiering. Mostly academic in nature, they represented some of Britain and Ireland's finest mathematicians, scientists, and indeed artists (see Table 1).

Table 1: Notable Civilian Professors and Tutors at the Royal Military Academy, Woolwich

Professor/Tutor	**Subject**	**Service**
John Müller (1699 – 1784)	Artillery and Fortification	1741 – 1766
Thomas Simpson (1710 – 1761)	Mathematics	1743 – 1761
Paul Sandby (1731 – 1809)	Drawing	1768 – 1799
Charles Hutton (1737-1823)	Mathematics	1773 – 1807
Isaac Landmann (1741-c.1829)	Artillery and Fortification	1777 – 1815
Adair Crawford (1748 – 1795)	Chemistry	c.1788 – c.1890 (Professor)
William Cruickshank (d.1811)	Chemistry	1788 – 1804 (Assistant to Crawford)
Lewis Evans (1755 – 1827)	Mathematics	1799 – 1820
Peter Barlow (1776-1862)	Mathematics	1801 – 1847
Olinthus Gilbert Gregory (1774-1841)	Mathematics	1802 – 1838 (Professor from 1821)
John MacCulloch (1773 – 1835)	Chemistry and Geology	1803 – ?
Thomas Myers (1774 – 1834)	Mathematics	1806 - ? (Professor)
Samuel Hunter Christie (1784 – 1865)	Mathematics	1806 – 1854 (Professor from 1838)
John Bonnycastle (1751 – 1821)	Mathematics	1807 – 1821
Michael Faraday (1791-1867)	Chemistry	c.1820 – 1852
Thales Fielding (1793 – 1837)	Drawing	1828 – 1837
James Marsh (1794 – 1846)	Chemistry	1829 – 1846 (Assistant to Faraday)
Thomas Simpson Evans (1777 – 1818)	Mathematics	c. .1830 – 1810 (Assistant to Evans)
William Rutherford (1798 – 1871)	Mathematics	1838 – 1865
Sir Frederick Able (1827-1902)	Chemistry	1852 – 1888
James Joseph Sylvester (1814 – 1897)	Mathematics	1855 – 1870
John Callow (1822 – 1878)	Drawing (Landscapes)	1861 – 1865
Aaron Edwind Penley (1807 – 1870)	Drawing	1861 - 1870
Francis Bashforth (1819 – 1912)	Applied Mathematics	1864 – 1872
Morgan Crofton (1826 – 1915)	Mathematics	1870 – 1884
Sir Alfred George Greenhill (1847 – 1927)	Mathematics	1876 – 1908

The Academy's first headmaster was John Müller (1699–1784), a German immigrant with no practical military experience, who was apparently appointed on the strength of his publication, *A Mathematical Treatise* (1736), which he dedicated to the Master-General of the Ordnance [10]. During his tenure as Professor of Fortifications and Artillery, Müller authored numerous textbooks that purposely went beyond pure mathematics and mechanics. His books presented theoretical solutions for practical problems of structural engineering encountered during the construction of fortifications.

They included theories for masonry arches, strength of beams, and of earth pressure and stability of retaining walls. Further works also covered navigational astronomy, ballistics, hydraulics, and pneumatics [11].

Müller's efforts, together with those of Thomas Simpson (1710–61), Charles Hutton (1737–1823) and Isaac Landmann (1741–c.1829), established the philosophy in which applied mathematics and mechanics were developed deliberately and systematically. Thus, an institutional locus was established at Woolwich, where such endeavours found patronage. In addition to their instruction, many of Müller's successors also produced numerous textbooks based upon original research in mechanics [12].

Arguably the most influential of these publications was an *Essay on the Strength and Stress of Timber* (1817), produced by Peter Barlow (1776–1862). Barlow claimed that his study was commissioned by General William Mudge (1762–1820), then lieutenant-governor of the Royal Military Academy, for the purposes of educating cadets and officers. Although Barlow's work was flawed and subject to later criticism, it proved extremely popular throughout military and civilian circles, seeing five editions in Barlow's lifetime alone, with further revisions after his death.

Lesser-known publications include those by Hutton. His treatise *The Principles of Bridges* (1772) was inspired by his predecessors' involvement in the Blackfriars Bridge (1769) controversy, together with the spate of bridge failures at that time. As with Barlow, his work suffered from flaws that were typical of his time. Hutton attempted to apply the elementary laws of statics to analyse statically indeterminate structures, without appreciating that they could not be solved. Nevertheless, such early attempts sometimes yielded results that were sufficient for practical applications and were probably used in actual design practice [13]. Moreover, these efforts stimulated further research, fuelled by interactions between a growing group of likeminded men, which foreshadowed the professionalization of engineering [14].

In contrast, civilian engineers were yet to develop such a locus, although an attempt had been made in 1771 with the founding of the Society of Civil Engineers (later the Smeatonian Society of Civil Engineers). Bringing together prominent engineers, in addition to instrument-makers and other craftsmen, its effective early membership was maintained for many years at about twenty. Whilst they managed to amass a substantial collection of brooks, drawings, and reports [15], they remained silent on the education of engineers and over time the society became little more than a dining club. Eventually its perceived failings led to the foundation of the Institution of Civil Engineers in 1818, where prominent military engineers would play an active role throughout the nineteenth century.

Course Structure and Content

The course at Woolwich was broadly divided into two components, one theoretical and a second practical, both lasting up four years and undertaken concurrently. Cadets were divided into classes based upon their levels of competence, as judged by the professors, to ensure each cadet saw a steady and efficient progress [16].

The content was provided through a series of lectures and practical demonstrations, as in the case of gunnery and surveying. Cadets were assessed by both oral and written exams set by the professors. In addition, each cadet was issued with blank notebooks which were inspected monthly [17].

The theoretical course comprised of a Course of Mathematics and a Course of Fortifications. The mathematics included the topics of: Arithmetic, Algebra, Logarithms, Geometry, Application of Algebra to Geometry, Trigonometry, Heights and Distances, Analytical and Descriptive Geometry, Conic Sections, Spherical Trigonometry, Mensuration, Differential and Integral Calculus, Mechanics, Hydrostatics, Hydrodynamics, and Pneumatics. It was intended that the application of these principles was shown in the Professor's Course of Lectures on Natural Philosophy, with further examples of their application demonstrated throughout the practical classes [18].

The Course on Fortifications included further elements of geometry, together with theoretical and practical drawing, including perspective and measure drawings. Cadets were tasked with copying existing drawings and drafting new ones, using views around Woolwich and surrounding areas as a source. Drawing work extended to the preparation of plans, sections and elevations of ordinary buildings, annotated with colour to indicate the different materials and the technical names of each component [19].

The practical course involved exercises in surveying, gunnery and drills, in addition to instruction on riding and fencing. This "practical" course also included further lectures on chemistry, geology and metallurgy [20].

Language skills were also a key component. French was compulsory throughout with later decades offering the choice of Hindustani or German [21], before expanding to include Italian, Spanish and Russian [22]. According to Sir Francis Bond Head (1793–1875), Hindustani was rarely chosen, whilst entrance exam results continually exhibited a poor grasp of foreign languages upon entry [23]. Considering British schools were dominated by classical education, Woolwich provided officers with an ability to read and understand foreign texts, as evidenced by their numerous translations, an opportunity which seemed lacking in many of their civilian counterparts.

Effectiveness of Training

Whilst the provisions at Woolwich appear impressive on paper, experiences during subsequently military campaigns, particularly the Peninsula War (1807–14), exposed severe deficiencies, with the effectiveness of young officers heavily criticised. Moreover, those reflecting upon their service noted how ill-prepared they were for their range of duties, notably in the construction of buildings [24]. The exercises at Woolwich ultimately fell short of specific training in structural engineering and general architecture. Instead, such emphasis on mathematics reflects the Continental influence of the academy's early professors and moreover, the theoretical origins of bastion and star fortifications that attempted to circumvent advances in artillery and ballistics.

Regardless of its failings, Woolwich still represented the first attempts at the systematic instruction of engineers in the British Empire and moreover, provided the model for future military schools.

East India Company Military Seminary, Addiscombe (1809–61)

In British India, officers needed for the engineering corps were initially drafted from the infantry [25]. Finding this system unsatisfactory, the East India Company sought assistance from the Crown, eventually reaching an agreement whereby the Company paid for their cadets to study at Woolwich. This arrangement lasted until 1809, when the East India Company Military Seminary was founded at Addiscombe, Surrey.

Modelled upon Woolwich, Addiscombe was originally intended for the education of engineering and artillery officers. In 1827, however, it began admitting cadets for "general service", morphing into a hybrid of Woolwich and Sandhurst.

With no system of purchase in the East India Company's armies, admission followed the patronage system of nomination confirmed by a qualifying examination. Cadets were entirely gentlemen, many of whom came from families with relations already serving in India, ether in the civil service or the military. As with the Royal Engineers, a signification proportion were recruited from Scotland [26]. However, most recruits were of lower social standing. Despite evidence that some suffered from occasional prejudice, collaborations on later publications demonstrate that officers from both services enjoyed mutual respect at a professional level [27].

Professors and Tutors

Like Woolwich, most of the professors at Addiscome were civilians, including many prominent mathematicians and scientists (see Table 2). In later decades, officers returning from India provided instruction on surveying and fortifications.

Table 2: Notable Civilian Professors and Tutors at the East India Company Military Seminary

Professor/Tutor	**Subject**	**Service**
James Andrew (c.1774 – 1833)	Superintendent	1809 – 1822
John Shakespear (1774 – 1858)	Hindustani	1809 – 1829
Joseph Bordwine (d.1835)	Fortifications	1809 – 1835
William Frederick Wells (1762 – 1836)	Drawing	1813 – 1836
John MacCulloch (1773 – 1835)	Chemistry and Geology	1814 – 1835
Jonathan Cape (1793 – 1868)	Mathematics	1822 – 1861
William Sturgeon (1783 – 1850)	Science and Philosophy	1824 – 1850
Theodore Henry Adolphus Fielding (1781 – 1851)	Drawing	1826 – 1850
Charles Bowels (later Shakespear)	Hindustani	1829 – 1859
John Frederic Daniell (1790 – 1845)	Chemistry	1835 – 1845
John Christian Schetky (1778 – 1874)	Drawing	1836 – 1855
Alfred Wrigley (1818 – 1898)	Mathematics	1841 – 1861
David Thomas Ansted (1814 – 1880)	Geology	1845 – 1861
Edward Solly (1819 – 1886)	Chemistry	1845 – 1859
Aaron Edwind Penley (1807 – 1870)	Drawing (Later at Woolwich)	1851 - 1861
John Callow (1822 – 1878)	Drawing (Later at Woolwich)	1855 – 1861
Edward Frankland (1825 – 1899)	Chemistry	1859 – 1861

Course Structure and Content

The course at Addiscombe lasted only 2 years and placed mathematics above all other subjects, occupying an average 22 hours of the 54-hour academic week [28], and dominated the final examination with the emphasis increasing over time [29]. Taught through the tutorial system, the entire course covered mathematics (including natural philosophy), fortifications, artillery, military drawing and surveying, landscape drawing (and later photography), military tactics, religious instruction, and languages [30].

The course of mathematics included topics of: Algebra, the Binomial Theorem, Logarithms, Differential and Integral Calculus, Geometry (Planes and Solids), Analytical Geometry (including conic sections), Trigonometry (Plane and Spherical), and the analytical investigation of Trigonometrical Formulae. Further topics included: Natural Philosophy, Statics, Dynamics, Hydrostatics, Hydrodynamics, and Astronomy [31].

The course of Military Drawing and Surveying comprised the operations of laying down a skeleton map trigonometrically. Cadets were then instructed on how to fill in by aid of the compass route surveying, reconnaissance, levelling with spirit levels and barometers. The relatively minor course of Landscape Drawing covered the Elements of Perspective, Landscape, and Figure Drawing [32].

The languages covered at Addiscombe included French, Latin and Hindustani. The French course included the study of French works on military science, whilst Latin focused on selections of historical works. Lessons in Hindustani were intended to provide cadets with the ability to communicate with their subordinate workforce when they arrived in India.

Further lectures were given in Geology, Chemistry, Artillery, and additionally, the steam engine, and the application of mechanical powers to machinery.

When studying fortifications, Cadets were instructed in sand modelling, conducted within a covered building erected for the purpose, 60 feet long by 50 feet wide. First introduced in 1839, by then Assistant Professor of Fortifications Lt. Cook, R.N., F.R.S., this technique would see wider applications by officers in the design of large-scale infrastructure works across India and Egypt [33].

Effectiveness of Training

Despite its ambitions and the considerable expense outlaid by the East India Company, the failings at Addiscombe were legion, falling well behind the standards set at Woolwich. Discipline was problematic throughout the first decades, culminating in a culture of corruption [34]. Demand for engineers across India meant that the Company repeatedly selected cadets who failed to meet the required standards and would otherwise be sent to the artillery or infantry [35].

The standard of education was also questionable, as were the appointments of some professors. Possibly the most farcical was that of Charles Bowles. Appointed Assistant Professor of Hindustani at the age of 19, barely older than some of the senior cadets, Bowles had never been to India nor heard the language spoken [36]. It is therefore unsurprising that cadets hated their classes and failed to pick up the language before reaching India. Despite several efforts by the Company to improve the language skills of their officers, it is arguably one of Addiscombe's greatest failings. Especially, as the inability of many officers to fully understand their indigenous subordinates contributed to the Indian Mutiny (1857), which ultimately saw the East India Company lose control [37].

Any attempts at developing an institutional locus dedicating to furthering Indian engineering failed and Addiscombe was deemed surplus to requirements. The school closed its door to new cadets in 1858 when the Crown began absorbing the East Indian Company's engineers into the Royal Engineers.

Royal Engineer Establishment, Chatham (School of Military Engineering)

Rather than overhaul Woolwich, it was thought that the practical skills could be improved by introducing a two-stage system of education, whereby cadets would continue to receive a foundation in theoretical knowledge at Woolwich before progressing to a new establishment that focused entirely on the latter. In 1812, the Royal Engineer Establishment was founded at Chatham to provide the Royal Engineers with that second stage. Lasting approximately 18 months, the course was also offered to the East India Company's cadets, who joined after their initial training at Addiscombe.

Chatham owes its foundation and early development to the endeavours of General Sir Charles William Pasley (1780–1861), a veteran of the Peninsula War who gained first-hand experience of the deficiencies of training in military engineering. Pasley spent his early career employed in the construction of fortifications, before taking part in the Walcheren Expedition (1809), where he suffered severe injuries. Rendered incapable of further active duty, he used his convalescence for reflection and personal development, learning the German language and writing various treatises [38]. In 1810, Pasley and Sir John Fox Burgoyne (1782–1871) formed the 'Society for Producing Useful Military Knowledge', a small group of Royal Engineers intent on encouraging the theoretical and practical studies in military engineering. They formed the nucleus of a new generation of officers with their own ideas of what needed to be done, starting a trend that inspired later generations and characterised the nature of reform in the coming years.

Pasley's philosophy on education was to establish a system of self-instruction. Largely inspired by the work of the educationalist, Andrew Bell (1753–1832), Pasley was first motivated to improve skills related to military works in the field, especially amongst the sappers and non-commissioned officers [39]. As such, the early curriculum was geared towards that purpose. Later he would turn his attention to the knowledge gap surrounding the Corps' peacetime duties. Himself an advocate of employing the Royal Engineers in the construction of public works, the need to improve skills became pressing when the Board of Ordnance resumed responsibility for the construction and maintenance of barracks in 1822.

Architecture and Construction Technology

Many issues the Royal Engineers faced were the result of the divisions between the professions and the building trades. When Chatham was founded, architecture as a profession was predominately the pursuit of gentlemen who would write on the subject or subscribe to architectural publications [40]. Where architects were employed, they did not provide detailed drawings that would be expected of the same professionals today. Hence, there was a greater reliance upon the skill and knowledge of the clerk of works and tradesmen to produce the required details [41]. The key issue that the Royal Engineers faced in the early-nineteenth century is that they were a corps that consisted entirely of officers who were not in regular command of a troop of skilled artificers. Therefore, the deficiencies in their practical knowledge had greater consequences. Recognising this problem, the Board of Ordnance issued an order in 1825 that a course of Practical Architecture should be instituted at Chatham [42]. It became the first formalised educational programme in architecture and building construction found anywhere in the British Empire.

As Chatham's director, Pasley attempted to address this issue through the production of his textbook *Outline of a Course of Practical Architecture* (1826). Filled with numerous sketches of building details it focused mainly on traditional construction in masonry, partially brick. Contrary to suggestions by its title, Pasley did not attempt to outline rules for proportioning buildings and outright avoided discussion on decoration, which he regarding the reserve of 'professed architects' [43]. Instead, training in design involved copying architectural drawings from books and plans before exercises in measurement. Using published price books, cadets were expected to draft estimates for the expense of buildings based upon the drawings and specifications [44]. Considered sufficient to design common military buildings such as barracks, hospitals, and storehouses, Pasley's book inadvertently helped cement the Royal Engineer's reputation for designing dull buildings whilst furthering a dependence upon pattern books that is observed in the early public works of British India.

Pattern books, exemplified by the works of William Pain (1730–90), Peter Nicholson (1765–1844), and Thomas Tredgold (1788–1829), attempted to bridge the gap in technical knowledge between building trades and design professionals, primarily for the benefit of the latter. Largely following their format, Palsey acknowledged the assistance of some of the most eminent civil engineers and builders in the preparation of his textbook [45]. However, much of its content was undoubtedly based upon his extensive experimental works conducted at Chatham.

Indeed, developing experimental science in construction was a crucial objective of the Establishment. Building upon the efforts of Müller at Woolwich nearly a century earlier, Chatham provided the Royal Engineers with a place to carry out investigative work, furthering the development of rational design. Crucially, its instructors instilled the virtues of such methods and disseminated the necessary skills to its cadets who formed the basis of the next generation. Two key protagonists were Sir William Thomas Denison (1804–71) and Richard John Nelson (1803–77). Denison published numerous scientific and technical papers throughout his career and was instrumental in establishing the Corps' leading technical journal in 1837, Papers on Subject Connected with the Duties of the Corps of Royal Engineers. Similarly, Nelson was a prolific author and keen advocate of self-instruction, publishing guidance for junior officers serving in remote locations.

Mid-Nineteenth Century Reforms

By the mid-1850s, however, the effectiveness of military engineers was again brought into question. The Crimean War (1853–56) exposed severe deficiencies across all levels within the British Army, from outdated tactics to the shambolic care of wounded soldiers and drew attention to these conditions at home. Reporting in 1861 and 1863, the newly formed Barracks and Hospitals Commission published a damming critique of construction and state of military buildings, for which the Royal Engineers were responsible. In 1855, the Board of Ordnance was abolished, and the Royal Engineers placed under the newly formed War Department. Shortly after, the Indian Mutiny (1857) saw the collapse of the East India Company and preparations were made to transfer its forces to the Crown. Doubling in size, the Royal Engineers were now faced with the challenges of public works in British India, whilst needing to address their existing shortcomings.

Commissions focusing on military education carried out in 1857 and 1862 concluded that whilst the theoretical education of officers was sufficient, their practical education was inadequate. Owing to the division of training between Woolwich and Chatham, the critique was targeted at the latter. Despite Pasley's earlier efforts, the Royal Engineers appeared incapable of educating their own. Moreover, the Establishment he founded appears to have gone into decline following his departure. Major-General Edward Renouard James (1833–1909), who entered Chatham in 1851 [46], later claimed that "the average man left Chatham incapable of designing or superintending the erection of the simplest work [47]." Whether an exaggeration of not, action was taken, and the commissioners' recommendations implemented. Under the new direction of Sir Henry Drury Harness (1804–83), officers such as Henry Wray (1826–1900), Henry Cooper Seddon (1837–1911), and Henry Young Darracott Scott (1822–83) arrived at Chatham. They brought a fresh impetus and practical experience of erecting public buildings, especially Wray who reformed teaching practices with a firm idea of an officer's role in design [48]. Moreover, these officers did much to advance our understanding of material science through experimental work that they disseminated through their own technical manuals.

In later decades, Chatham established a series of schools, focusing on the diverging specialisms that were developing in the civil sphere. These included the schools of Estimating and Construction, Surveying, Electricity, Telegraphy, and Balloons. Each played host to rotor of guest civilian lecturers who were brought in to provide up-to-date knowledge of the latest developments in civilian engineering and technology.

The Royal Engineer Institute – Focus on Military Science

Reform resulting from military calamities would eventually have a detrimental effect upon the Corps' wider contributions to science and engineering. By the 1870s, a view had developed within the army, which according to Captain W. A Ross of the Royal Artillery, thought that "scientific study of almost any kind, is derogatory to their military character [49]". The foundation of the Royal Engineer Institute at Chatham, with its remit to focus specifically on military science, signalled an intent towards that direction. Moreover, the army's inability to provide enough engineers for the public works programmes across the empire would see them relieved of those duties.

In the latter decades of the nineteenth century, military education went from a broad-based engineering education towards an explicitly martial nature. Whenever conflict for space within the curriculum arose, aspect focusing on civil works were sacrificed [50]. Some leading officers continued to advocate the benefits of scientific study, beyond those immediately necessary for carrying out military duties, and repeatedly push back against the countermovement of masculinity. However, their efforts were largely in vain.

Summary

From their foundation in 1741, the education of the Royal Engineers and their Indian counterparts consisted of a structured curriculum, intent on developing a solid understanding of mathematics and scientific principles. In contrast, civilian

engineers who were not entirely self-taught were educated through non-structured, un-regulated apprenticeships. Whereas civilian engineers developed their expertise based upon observation, precedence, trial-and-error and manual dexterity, military engineers were early proponents of rational design methods.

Efforts at Woolwich, Addiscombe and Chatham helped establish an institutional locus that furthered the engineering sciences, especially materials science. They nurtured ideas, provided facilities to carry out research, and the means to disseminate their findings through their own publications. No equivalent establishment was available to civilian engineers in the nineteenth century.

Both civilian and military engineers acknowledged their own deficiencies, however, the latter were more open to reform. Throughout the nineteenth century, military engineers sought to improve their practical knowledge and learn from their mistakes. Moreover, they readily adopted knowledge and technology from overseas. In contrast, civilian engineers were slow to embrace theoretical developments, holding the firm belief that British civilian engineers were the envy of the world, by virtue of the fact they were in such high demand. Furthermore, the British education system remained largely rooted in classical education and lagged behind European countries with regards to science.

Ultimately, the shift from apprenticeships to university-based education, followed by post-graduate qualification through experience, saw the civilian engineering profession adopt the two-tier system that the military developed over 100 years ago.

References

[1] F. G. Guggisberg, *The Shop: The Story of the Royal Military Academy*. London: Cassell & Co., 1900.
[2] Royal Warrant, 30 April 1741. Quoted in: Douglas William Marshall, The British Military Engineers 1741-1783: A Study of Organization, Social Origin, and Cartography. PhD Thesis, University of Michigan, 1976, p.87.
[3] Sir Francis B. Head, *The Royal Engineer*. London: John Murray, 1869, p. 1
[4] John Black, *The development of professional management in the public sector of the United Kingdom from 1855 to 1925: the case of the ordnance factories*. PhD Thesis, The Open University, 2000, p. 52
[5] This assessment is based upon an analysis of published obituaries and memoirs of numerous Royal Engineers.
[6] Douglas William Marshall (see note 2).
[7] Fleeming Jenkyn, 'A Lecture on the Education of Civil and Mechanical Engineers in Great Britain and Abroad', In: Institution of Civil Engineers, *The Education and Status of Civil Engineers in the United Kingdom and Foreign Countries.* London: 1870, pp. 198-204.
[8] Claire Jean Cookson-Hills, Engineering The Nile: Irrigation and the British Empire in Egypt, 1822 – 1914, PhD Thesis, Queen's University (Kingston, Ontario), 2013, p. 62.
[9] H. Moseley, H., *Report on the Examination for Appointments in the Royal Artillery and Engineers, Held at King's College, London on the First of August, 1855, with Copies of the Examination Papers*. London: Harrison, 1855.
[10] John Müller, *A Mathematical Treatises: Containing a System of Concic-Section; With the Doctorine of Fluxions and Fluents, Applied to Various Subjects*. London: T. Gardner, 1736.
[11] Harold I. Dorn, *The Art of Building and the Science of Mechanics: A Study of the Union of Theory and Practice in the Early History of Structural Analysis in England*. PhD Dissertation, Princeton University, 1970, p. 142.
[12] ibid., p. 148.
[13] ibid., p. 151.
[14] ibid., p. 151.
[15] A. W. Skempton and Esther Clark Wright, 'Early members of the Smeatonian Society of Civil Engineers', *Transactions of the Newcomen Society*, Vol. 44, No.1, 1971, pp. 23–47.
[16] Lt. Col. William Yolland, Lt. Col. Symth, The Rev. W. C. Lake, *Report of the Commissioners Appointed to Consider the Best Mode of Re-Organising the System for Training Officers for the Scientific Corp*. London: HMSO, 1857, p. 289.

[17] John Michael Weiler, *Army Architects*, PhD Thesis, University of York, 1987, p. 8.
[18] Lt. Col. Yolland, et. al, (note 16), p. 289.
[19] John Michael Weiler (note 17), p. 9.
[20] ibid., p. 8.
[21] Lt. Col. Yolland, et. al, (note 16), p. 266. Sir Francis B. Head (note 3), p. 13.
[22] Captain Walter H. James, late R.E., 'Military education and training', *Royal United Services Institution Journal*, Vol. 26, 188), pp. 369-95.
[23] Captain Walter H. James (note 22), p. 372.
[24] Anon. *Our Military Engineers: Being an Inquiry into the Present State of Efficiency of the Corps of Royal Engineers*. London: Judd & Glass, 1860.
[25] Colonel H. M. Vibart, *Addiscombe – Its Heroes and Men of Note*. Westminster: Archibald Constable & Co., 1894, p. 1.
[26] A. Cameron Taylor, *General Sir Alex Taylor G.C.B., R.E, His Times, His Friends, and His Work.* Vol. 1. London: Williams and Norgate, 1913, p. 3
[27] John Michael Weiler (note 17) p 5.
[28] Major William Broadfoot, 'Addiscombe', *Blackwood's Edinburgh Magazine*, Vol. 153, 1893, pp. 647-57.
[29] Colonel H. M. Vibart, (note 25), pp. 154-155.
[30] Lt. Col. Yolland, et. al, (note 16), p. 266.
[31] ibid., p. 266.
[32] ibid., p. 266.
[33] Colonel H. M. Vibart, (note 25), p. 131; Claire Jean Cookson-Hills (note 8), p.65-6.
[34] Major William Broadfoot (note 28), p. 653.
[35] Lt. Col. Yolland, et. al, (note 16), p. 269
[36] Colonel H. M. Vibart, (note 25), p. 95.
[37] J. M. Bourne, 'The East India Company's Military Seminary, Addiscombe, 1809 – 1858', *Journal of the Society for Army Historical Research*, Vol. 57, No. 232, 1979, pp. 208-10.
[38] Captain H. W. Tyler, 'Memoir of the late General Sir C. Pasley, K.C.B., R.E.', *Papers on Subjects Connected with the Duties of the Corps of Royal Engineers, New Series,* Vol. 12, 1863, pp. i – xv.
[39] Colonel Bernard R. Ward, *School of Military Engineering, 1812-1909*, Chatham: Royal Engineers Institute, 1909, p. 9.
[40] David T. Yeomans, 'Early carpenter's manuals 1592 – 1820', *Construction History*, 2 (1986), pp. 13 – 33.
[41] ibid., p. 29.
[42] Colonel Bernard R. Ward (note 39), p. 16.
[43] Shanti Jayewardene-Pillai, *Imperial Conversations: Indo-Britons and the Architecture of South India*. New Delhi: Yoda Press, 2007, p. 181.
[44] Charles William Pasley, *Outline of a Course in Practical Architecture*, Chatham: 1862, p. 1-12; John Michael Weiler (note 17), p. 13-14.
[45] Charles William Pasley (note 44), p. 2.
[46] Colonel R. H. Vetch, 'Memoir: Major-General Edward Renoud James, Royal Engineers', *Royal Engineer Journal*, Vol. 12, No. 3, 1910, pp. 191-206.
[47] Quoted in: Colonel Bernard R. Ward (note 39), p. 19.
[48] Colonel Bernard R. Ward (note 39), p. 19.
[49] Captain W. A. Ross, late R.A., 'The cultivation of scientific knowledge by regimental officers of the British Army,' *Royal United Service Institution*, Vol. 16, 1873, pp. 774-81.
[50] Claire Jean Cookson-Hills (note 8), p.71.