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Delineating a Rational Profession: The Machine Drawings of Engineers in Early Nineteenth-Century Britain*

In the nineteenth-century, mechanical drawings presented some of the most distinctive and widespread visual statements of the 'machine dreams' of industrialization[1]. In Britain the genre of engineering drawing developed rapidly with little official training or direction; engineers and draughtsmen were self-trained in drawing, fashioning their own status in a competitive visual economy[2]. Technical representations in large manufacturing enterprises such as heavy engineering or civil infrastructure projects were not simply a means of

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[1] H. Sussman, 'Machine Dreams: The Culture of Technology,' *Victorian Literature and Culture*, 28:1, 2000, pp. 197-204.

[2] This was in contrast to the more regulated state-funded technical education systems in France and other European countries; see J.K. Alexander, *The Mantra of Efficiency: From Waterwheel to Social Control*, Baltimore: Johns Hopkins University Press, 2008; D.S.L. Cardwell, *The Organisation of Science in England*, London: Heinemann, 1972; J.W. Edmonson, *From Mécanicien to Ingénieur: Technical Education and the Machine Building Industry in Nineteenth-Century France*, New York and London: Garland Publishing, Inc., 1987; J.H. Weiss, *The Making of Technological Man: The Social Origins of French Engineering Education*, Cambridge, Mass.: MIT Press., 1982. For accounts of the British experience, see K. Baynes and F. Pugh, *The Art of the Engineer*,Guildford: Lutterworth, 1981 and C. Fox, *The Arts of Industry in the Aage of Enlightenment*, New Haven and London: Yale University Press, 2009.

presenting oneself to the general public, however, but functioned more directly as a means to immediate power in the workplace, a method of exerting control over subordinates at a distance. Distinctive styles of engineering drawing, well known from the work of various celebrated figures such as John Smeaton or James Watt, emerged within the period of 'industrial enlightenment' around 1800; a public culture where representations alongside exhibitions and lectures created a meaning for machines that merged the mechanical and the philosophical under the banner of improvement[3]. This era of industrial mysticism and invention at the very end of the eighteenth century is the counterpart of the French experience of utopian revolution and encouragement of manufactures in the same period.

Despite the utopian mission of 'improvement,' the industrial enlightenment was not a jolly consensus; engineers were trying to build professional status as investigators in the rational mechanical science of construction and manufacture, aiming to fend off, variously, natural philosophers, other technical professions, and, increasingly, lower aspiring ranks within their own field. Beyond Britain, there was further national and military conflict that marred the universal cosmopolitan notion of a republic of science. Despite the rational stance promoted by engineers on both sides of the Channel, we see equally strong elements of chaos—revolutionary ideological conflict, economic blockade, and war—creating opportunities for technical professions.

This article considers some surprising artefacts, drawing machines, which at first glance appear to be ludicrously at odds in their miniature scale with the substantial and heroic feats of material production and construction (as in bridges, road systems, or canals) that are supposedly the engineer's unique field of operations[4]. Nevertheless, we see that from the late eighteenth

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[3] L. Stewart, 'A Meaning for Machines: Modernity, Utility, and the Eighteenth-Century British Public,' *The Journal of Modern History* 70 (2), 1988, p.291; J. Mokyr, *The Enlightened Economy: An Economic History of Britain 1700-1850*, New Haven: Yale University Press, 2009.

[4] C. MacLeod, *Heroes of Invention: Technology, Liberalism and British Identity, 1750-1914*, Cambridge: Cambridge University Press, 2007.

century through to around 1830, engineers, draughtsmen, and other groups in Britain entered into a competitive frenzy to invent mechanical drawing aids. These instruments were displayed in useful arts publications such as the *Transactions* of the Society of Arts both as objects described in words and pictures, but also through the traces of their use in a very self-referential way[5]. In actual use, many of these devices were fiddly and temperamental, as difficult to build as to operate, prompting the question, why did engineers bother to invent all this paraphernalia? I argue that these toy-like devices contributed just as much as bridges or gargantuan steam-powered machines did to the self-fashioning of engineers and engineering by bringing together several spheres of operation—from the private office to the factory floor—through the medium of publication. Just as the professional engineers developed a range of literary practices—through reports, or popularizing accounts of their work—so they also acted as visual technicians, shaping the genre of technical representation[6]. 'Machine drawing' created distinctive marks that formed the machine aesthetic in print, working in feedback with developments in technical visual communications in the workplace.

To those who see technical drawing as emanating from the 'mind's eye' of the engineer, illustrations are frequently, and misleadingly, characterised as peripheral or non-serious productions[7]. But in fact many different types of mechanical engineers worked as visual technicians and were concerned with

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[5] The Society of Arts was founded in1754 by William Shipley (1715-1803) as the 'Society for the Encouragement of Arts, Manufactures, and Commerce,' later the Royal Society of Arts. The *Transactions*, the journal of the Society, circulated details of the latest inventions, the latest developments in art and design, and scientific inventions, and also published lists of the latest money prizes (premiums) and medals available (*Transactions* of the Society for the Encouragement of Arts, Manufactures, and Commerce, 1789-1845). See also R. Yeo, *Encyclopaedic Visions*, Cambridge: Cambridge University Press, 2001, who discusses British initiatives such as the *Encyclopaedia Britannica* (first edition 1768-1771), Abraham Rees's *Cyclopaedia* (1802-1820), and the *Edinburgh Encyclopaedia* of David Brewster (1808-1830).

[6] B. Marsden, 'Re-reading Isambard Kingdom Brunel: Engineering Literature in the Early Nineteenth Century,' B.Marsden, H. Hutchison and R. O'Connor, eds., *Uncommon Contexts: Encounters between Science and Literature, 1800-1914*, London, Pickering & Chatto, 2013, pp. 83-109.

[7] E.S. Ferguson, 'The Mind's Eye: Non-Verbal Thought in Technology,' *Science* 197 (August 26, 1977), pp. 827-36.

technologies of representation on paper, using and inventing drawing machines to manage the literature of professional presentation. While it goes without saying that engineers also devised much of the heavy equipment of industrial knowledge such as paper making machines and printing presses, this was work behind the scenes. With drawing aids, by contrast, engineers inserted their presence directly into the flow of knowledge. They supported their writings with new kinds of image-text combinations and they asserted new forms of drawing skill, where paradoxically the traditional hand craft of the artist was no longer of value. Engineers emphasized the connections between industrial invention, engineering, and printing. In publications that aimed to encourage the useful arts of manufacturing, printing served as a metaphor for industry. Printing appeared to the prophets of industrialization to enact the dream of exact repeatability in the production of multiples. Through the efforts of popularisers such as Charles Babbage, analogies made between printing and industrial production in the nineteenth century became well-worn figures of speech turning endlessly back on themselves[8].

Engineers thought a lot about how to reproduce images both in the workplace and for publication. Exact copies were valued, because images had to be shared and distributed. Technical drawings had contractual status, setting out a promise to clients about something that was going to happen in the future, so draughtsmen aimed for fixed indelible markings that were as unambiguous as possible—for example through using conventional lines of uniform width. Unlike artistic drawing, technical drawing was intended to be a mechanical process that could be reproduced at will and by anyone—the most humble apprentice was expected to copy and reproduce the same drawings as the elite engineer. For these operations simple draughtsmen's tools such as compass and ruler acted as the most basic reprographic machines, encouraging uniformity and discipline. Engineers also used print as a medium to display allegiance with communities of knowledge and skill beyond the factory or

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[8] D. McKitterick, *Print, Manuscript and the Search for Order, 1450-1830*, Cambridge: Cambridge University Press, 2003, p. 166.

construction site. In the pages of the *Transactions* of the Society of Arts we see contributors moving around in a carousel of interchangeable roles that join on to other social networks, as inventors, engravers, or draughtsmen. The engraver Wilson Lowry for example, was a member of the Royal Society and a founder member of the Geological Society. The *Transactions* enlisted celebrity engineers such as Henry Maudslay and Marc Isambard Brunel, famous for their wartime invention of automatic block making machinery for the Navy, as referees to report on new inventions[9].

Drawings for print and for production were two separate genres, different, but in dialogue. Mechanical engineers developed their drawing languages amongst related technical professions, and started that training in the schoolroom. Drawing was a means of professional expression with ruler and compass as basic mark making aids, supported and further elaborated with more specialized equipment, creating a focus on the mechanics of drawing where even seemingly basic and mundane objects like straightedge rulers could gain talismanic status[10]. At a simple level, engineers invented and sold drawing devices because they were entrepreneurs. There was an expansion in trade for optical entertainments in the late eighteenth century, developing alongside new workaday products to meet a market demand for surveying or military equipment, for example when David Napier or James Watt, better known for their steam powered engines, also developed perspective drawing machines, optical aids towards observational drawing. Here we see continuity of skills as well as networking, for many early engineers trained as instrument makers and

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[9] Maudslay and Brunel had been associated together in developing an automated mechanical technique for making standardised pulley blocks for the Naval Dockyards during the Napoleonic wars. Pulley blocks were complicated wooden connectors used in ship rigging, extremely intricate to shape and put together by hand, but used by the thousand on every ship. Maudslay and Brunel both provided a report on a drawing machine called a 'curvagraph' invented and used by one of Brunel's draughtsmen, Mr. Warcup in 1817 (Society of Arts *Transactions* 1817, Volume 35, pp. 109-112).
[10] M. Hambly, *Drawing Instruments, 1580-1980*, London: Sotheby's Publications, 1988.

developed their practice through activities such as surveying, cartography and engraving[11].

Other inventions though had a different function; they were not optical aids, but instead were literally drawing machines that automatically generated complex forms supplanting the skill of the human hand, for example with the invention of the rose engine in security printing for banknotes, or when James Watt, late in life, worked on a sculpting machine inspired by the sight of 'medal engraving' machines[12]. Many specialized instruments developed in association with this technical visual culture with artfully crafted portmanteau names such as elliptograph, curvagraph, or centrolinead displayed the mechanical arts in a reflexive manner, perversely turning the more normal progression of technical drawing as a proposal for a finished machine on its head. Instead machines made drawings.

This article will introduce a range of devices from apparently simple machines for ruling lines through to more complex offerings. While the names may be strange, the appearance of many of these instruments will be familiar to

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[11] Instrument makers promoted their wares in shops, lectures and in print. For example, George Adams, Snr. (c. 1720-1773) was mathematical instrument maker to George III, and also supplied drawing and surveying instruments to the Board of Ordnance and to the East India Company. His son George Adams, Jnr. (1750-95), continuing the business, published *Geometrical and Graphical Essays* (1791) where he explained how to use and where to purchase drawing instruments (Hambly, *ibid*., pp. 44-5); the subsequent updated 1813 edition included images of current stock, and an extensive trade catalogue at the end of the book. Instrument makers, surveyors and cartographers were closely involved with new publishing enterprises of this period, with the production of encyclopaedias, maps, and atlases in cities such as London and Edinburgh (see for example A. McConnell, 'From Craft Workshop to Big Business—The London Scientific Instrument's Response to Increasing Demand, 1750-1820,' *London Journal* 19 (1), 1994, pp. 36-53 or T.N. Clark, A.D. Morrison-Low, and A.D.C. Simpson, *Brass and Glass: Scientific Instrument Making Workshops in Scotland*, Edinburgh: National Museums of Scotland, 1989.

[12] Rose engines used the complexity of interchangeable gears harnessed to a rotating lathe action to generate the spirograph-like 'rose' patterns seen in **Figures 1 and 4**. For rose engines, see D.M Henshaw, 'Donkin's Pantagraph Engraving Machine with Rose Engine,' *Transactions of the Newcomen Society* Volume XV, 1934-5, pp. 77-84; for medal engraving, please note this term is confusing because it is actually a method of transcribing a low-relief image such as a sculpture or medal onto a two-dimensional printed surface. The process was also known as anaglyptography. A ruling machine with two connected needle-points was used in the process; one needle traced the surface in relief, the other needle inscribed a recording surface; see A. McConnell, *R.B. Bate of the Poultry, 1782-1847: The Life and Times of a Scientific Instrument Maker*, London: Scientific Instrument Society Monograph, 1993, pp. 29-31.

readers as images on the page, as typical examples of diagrams and illustrations from the era of 'useful knowledge' and the encyclopaedias. However, and to complicate the spirit of *textimage*, it is important to state that image-text analysis alone cannot fully provide a meaning for the machines or their images. Instead, it is necessary to examine the material circumstances of production by seeking out and handling surviving instruments in collections. Getting access to such archives is not easy, but the resulting encounters with the objects are irreplaceable. Handling these often obdurate objects forces new questions and approaches on the researcher, inviting new narratives about the interaction between procedures for making and using drawing equipment. Hands-on research showed that many devices were exceptionally troublesome to operate, and raised many other questions about the gap between the enthusiastic promotion of invention and their actual usefulness as drawing aids once realised. Nevertheless, this encounter also provided evidence to argue that these flawed machines—and the drawings they produced—did contribute just as much as large heroic projects did to the self-fashioning of engineers and engineering.

Ruling a straight line is such a basic operation it is almost invisible. But twentieth-century and contemporary perceptions of the straight line—seen as simple or totally boring—are misleading. In the late eighteenth and early nineteenth century straight ruled lines were instead the focus for inventive attention. In print, straight lines were energized through the well-known ruling machine invented by the engraver Wilson Lowry around 1790. Engravers embraced Lowry's machine, with its unvarying and mechanically spaced lines, that, according to the *Transactions* of the Society of Arts of 1826, was as useful 'as the steam engine is to the manufacturer.' In collaboration with the technical draughtsman John Farey, Lowry's diamond etched lines, praised for their 'admirable degree of regularity and sweetness' crept across thousands of plates for encyclopaedias, self-help publications and mechanics' magazines[13]. The extreme accuracy and neatness of Lowry's drawing machine led to a kind of technological brinkmanship, evidenced by the note of desperation in engraver Edmund Turrell's announcement to the Society of Arts of a modified drawing board with an especially smooth surface to cope with the frightening perfection of machine-ruled lines[14]. More complex forms, such as ellipses, offered an equally powerful lure to inventors[15]. While it was often claimed that drawing machines were simply the most efficient means of image production, the excessive and superhumanly regular forms they made went far beyond functionality.

Drawing machines and the apparent geometrical perfection of drawings made by these means raised all kinds of material and philosophical conundrums. In technical drawing on paper, a ruled line is a command to produce a straight edge or flat plane surface; in short it denotes something that has to be achievable in the real world. Much basic equipment of industrial production relied on reliable flat planes, although a flat surface was one of the hardest forms to produce[16]. In everyday engineering practice, and certainly up

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13 'Memoir of Wilson Lowry,' *Imperial Magazine* Vol. VII February 1825, pp. 113-128; T.H. Fielding, *The Art of Engraving*, London: Ackermann, 1841; B. Hunnisett, *A Dictionary of British Steel Engravers*, Leigh-on-Sea: F. Lewis, 1980.

14 Society of Arts *Transactions* 1816: 139-40.

15 At least three ellipse-drawing devices jostled politely for the attention of the Society of Arts before 1820: Cubitt's ellipsifex (Society of Arts *Transactions* 1816, pp. 131-7); Joseph Clement's instrument for drawing ellipses, which was awarded a Gold Medal (Society of Arts *Transactions* 1818, pp. 133-77); and John Farey's elliptograph, Society of Arts *Transactions* 1813, pp. 117-130).

16 From George Adams Jr. in the 1790s, to A.B. Kempe in the 1870s, to Bryant and Sangwin in 2008, engineers, mathematicians and inventors have reiterated the fact that making a straight line (in chalk, metal, wood) is difficult, challenging, nay physically impossible. In the early nineteenth century, flat planes and straight edges were used for steam engine valves, lathe beds or printing press tables. The effort to master techniques for making plane surfaces became one of the standard tropes of industrial hagiography. So the first systematic user of the accurate standard plane for testing surfaces, Henry Maudslay, was cited over and over again in different industrial biographies, whilst inventors and owners of planing machines, such as Richard Roberts or Joseph Clement, could earn a substantial fortune from hiring out their magic by the hour. See George Adams, Jr. [1791], *Geometrical and Graphical Essays*, Fourth edition, corrected and enlarged by William Jones London: W.& S. Jones, 1813; A.B. Kempe, *How to Draw a Straight Line; A Lecture on Linkages*, London: Macmillan and Co., 1877; J. Bryant and C. Sangwin, *How Round Is Your Circle?*, Princeton: Princeton University Press, 2008; J. Cantrell

to the later part of the nineteenth century, straight edges were more often produced by empirical methods. In this artisanal approach, the method for making a flat plane or straight line is to shape by eye, checking with spirit levels and so on, and then (for flat planes) to test three planes against one another, slowly eliminating hollows or bumps with a file until the edge is as flat as possible. Craftsmen held on to their 'master' testing edges very carefully and avoided chipping or denting them. But this poses the logical problem of retrogression: where does your first straight edge come from? George Adams Jr., instrument maker and author of *Geometrical and Graphical Essays*, made a great fuss about the material difficulties of cutting a line onto the surface of his mathematical instruments in order to assert his personal craft expertise, writing at a time when it was agreed by everyone that straight lines and flat surfaces were a considerable manufacturing challenge. Rather than being easy, unskilled, or routine, Adams made it clear that it was particularly difficult to place and draw a straight line, finding it 'impossible to draw a knife a second time against the rule, and cut within the same line as before.' Adams used beam compasses to cut short intersecting arcs, raising up a metal bur, and thence by fingertip groping for the intersection ('you may therefore feel what you cannot see … they will guide'), and thence, still working by feel, moving on to form further points[17] As a celebrated craftsman, Adams was reinforcing the trust of his customers in the accuracy of his work through this laborious description. The art of making reliable instruments with regular subdivisions of linear and angular measurements was known as graduation; we see from the article on this topic in the *Edinburgh Encyclopaedia* that such trusted and tested measuring instruments were important not just in their own right, as prized possessions, but also as the parents of many descendants, for they were then used to generate copies, and indeed, 'copies of copies.'[18]

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and G. Cookson, eds, *Henry Maudslay & The Pioneers of the Machine Age*, Stroud, Gloucestershire: Tempus Publishing, 2002, pp. 28; 94; 111.

17 Adams, 1813, pp. 112-13.

18 'Graduation,' *Edinburgh Encyclopaedia*, Volume 10, 1830, pp. 348-384.

However, as already noted, and despite the importance given to accurate lines and plane surfaces in industrial propaganda and in printed images, in many working situations in manufacturing, line marking continued in reality to be provisional and empirical. Straight lines were twanged in with chalk lines or plumb lines, while curves, so long as they passed through a few crucial calculated points, were laid in by eye or by bending elastic curves of whalebone, steel or wood. In drawing offices, only a few rulers were carefully and exquisitely made. The majority, as used by tradesmen or lowly draughtsmen in the Board of Ordnance (the state military cartographers), were simple wooden rules with unprotected edges[19]. The marks these laid down were accepted as provisional and merely conventional, their exactitude supplemented with written dimensions, but nevertheless most suitable for purpose. These circumstances only reinforce our initial question; why put so much effort into creating machines that drew to an unnecessarily ideal standard?

More specialized instruments such as ellipse drawing machines, offer similar puzzles. New inventions such as the John Farey's Elliptograph were smooth automatic mechanisms that used very familiar geometric principles. Draughtsmen were already accustomed to drawing this curve by various methods with very simple resources[20]. So why were such expensive and fiddly new instruments invented by so many people, and why were they in demand[21]? Comparing two devices for drawing ellipses from museum collections, the trammel and the elliptograph, gives more idea about the objects in use, and

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[19] J.R. Millburn, 'The Office of Ordnance and the Instrument Making Trade in the Mid-Eighteenth Century,' *Annals of Science* 45, 1988, pp. 221-293; J. Rabone, Jr. [1866], 'Measuring Rules' in D. J. Hallam, *The First 200 years—A Short History of Rabone Chesterman Limited*, Birmingham: Rabone Chesterman, 1984, pp. 131-4; I. Watts, W.J.M. Rankine, F. K. Barnes, and J. R. Napier, *Shipbuilding, Theoretical and Practical*, London and Glasgow: William Mackenzie, 1866.

[20] At the most basic level, one can draw an ellipse by laying a loop of string around two pins or sticks (placed in the foci) and drawing within that loop. Other simple devices include the trammel (discussed below).

[21] In 1851, for example, the catalogue of Elliot Brothers' instrument manufacturers gave the price of a trammel at £2-12s-6d, whilst Farey's elliptograph cost £7-17s-6d; see J.F. Heather *An Elementary Treatise on Descriptive Geometry*, London: John Weale, 1851: appendix.

helps us to differentiate between them[22]. The moving circles in the elliptograph are only 10 cm across, so it drew ellipses that are no larger than 7cm in length, whereas the trammel can throw out a curve up to ten times that size, of around 70 cm. Larger curves from the trammel were used to make workshop and production drawings, as a step to making objects, whilst the images drawn by the elliptograph are small because they were intended purely as a step towards printed images. John Farey, the inventor of this particular device, developed and expanded the visual language of engineering in a distinctive manner by using machine aids deliberately, as engineering projects that served his own professional trajectory as a writer-engineer[23]. So, when employed as a draughtsman for Rees's *Cyclopaedia* he captured images such as John Smeaton's London Bridge waterwheel for the London Waterworks in pictorial perspective from a slight oblique angle, first sketching the machine on site with the help of a Wollaston-type camera lucida, using pencil. Farey's underdrawing at this point was extremely sketchy, but he transformed his rough notation when he worked it up in ink, relying on mechanical drawing aids to create an effect of accuracy (ranging from ruler and compass, through to his own inventions, such as the elliptograph and centrolinead)[24]. He announced his pragmatic method, using machines alone, without too much calculation or observation, in his article 'Drawing Instruments' in Brewster's *Edinburgh Encyclopaedia*:

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22 I thank the National Museums of Scotland, Edinburgh, for access to the John Farey Elliptograph (c. 1812) T.1969.16 and George Adams Semi-elliptic trammel (c. 1775) T.1897.185.

23 John Farey, Jr. achieved public eminence as an engineering consultant and patent agent; for example giving evidence to the Select Committee on Patent Laws in 1829. He became a member of the Institution of Civil Engineers in 1826, and towards the end of his life acted as a juror for the machinery section of the Great Exhibition of 1851. However, his later professional standing was based on the training he received by observing machinery and developing techniques of writing and draughtsmanship while working on Abraham Rees' *Cyclopaedia* (1802-1819) from 1805 in collaboration with Wilson Lowry the steel engraver. See A.P. Woolrich, 'Farey, John (1791-1851),' *Oxford Dictionary of National Biography*. Ed. H. C. G. Matthew and Brian Harrison, Oxford: OUP, 2004. Online ed. Ed. Lawrence Goldman on the Oxford Dictionary of National Biography.

24 A.P. Woolrich, 'John Farey, Jnr., Technical Author and Draughtsman: His Contribution to Rees' Cyclopaedia,' *Industrial Archaeology Review* XX, 1998, pp. 49-67; A.P. Woolrich, A.P., 'John Farey and the Smeaton manuscripts,' *History of Technology* 10, 1985, pp. 181-216.

All that is required, as data for describing any ellipsis… is to sketch them in pencil on the paper, and mark, by the compasses, the four points upon each curve where its two diameters intersect it. Place the instrument [the elliptograph] upon the paper in such a position, that, by estimation of the eye, the centre of the four rulers seems to coincide with the centre of the intended ellipse[25].

Farey is quite clear here; in place of hand-eye coordination skills that were previously valued, he puts an engineered solution to the task of observational drawing, deputizing his conceptual knowledge to the machine. Although many artists had used such devices in a secretive way, Farey did not hide this aspect of his practice. Instead, he celebrated mechanical drawing aids, and shared these techniques through publication. His unvarying inked lines, laid in by machine and diamond point, were the 'chaste' product of a self-registering technology that had no need of hand crafting skills and gained authority because they were mechanically drawn—so Farey asserts a new and opposite virtue from Adams's embodied craft skills. Farey's drawing machines supplanted personal body discipline, and instead asserted the ability to control and command endlessly repeatable and accurate copies.

Engineers developed various spheres of operation: in the two-dimensional world of paper where they presented 'engineering' in texts and images, as well as in the three-dimensional world of material structures, professional combat and factory organization[26]. Machine drawing displayed new and specific professional skills that marked a clear separation from artistic and even design practice, where such aids would only be called on covertly.

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[25] 'Drawing Instruments,' *Edinburgh Encyclopaedia* volume X 1830, pp. 121-132; p. 132.

[26] John K. Brown, building on the work of writers such as Steven Lubar, notes that while Victorian engineers had several motivations for using mechanical drawings (that he characterizes as 'instrumentalist, professionalizing, and political'), they did not own up to all of these elements. By contrast, the instrumentalist view that drawings are simply a rational vehicle for designing and manufacturing was a strategic form of self-presentation commonly adopted by engineers and historians of drafting such as Baynes and Pugh (1981). See Lubar, Steven, 'Representation and power,' *Technology and Culture*, Supplement to Volume 36, 1995: S54-S74; J.K. Brown, 'Design Plans, Working Drawings, National Styles: Engineering Practice in Great Britain and the United States, 1775-1945,' *Technology and Culture* 41 (2), 2000, pp. 195-238.

Inventing and using drawing machines also announced allegiances with other activities such as instrument making and the sciences of accurate measurement and making across a whole range of activities from practical technology to science. Ruling machines made diffraction gratings and fancy buttons for gentlemen; accurate division was the goal of precision screw manufacture in both industry and astronomy, while elliptical and rose-engine devices aided both the close contemplation of gear workings or the cosmic tracks of celestial bodies[27].

Fine measurements and reliable standards in both machines and in drawings were of course central to the development of metrology and standardization later in the nineteenth century[28]. But at the turn of the nineteenth century, the claim to be able reliably to execute known geometrical forms in the real world also carried weight, notably in the promotion of James Watt's condensing steam engine that was sold on the basis of improved fuel economy. His engine helped the user to save money on fuel due to marginal improvements in performance based on theorized control of form. Superhumanly neat inscriptions on paper functioned as a promise to deliver such custom-made designed goods in the material world.

So on the one hand, machine drawing was propaganda about control, an articulation of the virtues of standardization and repeatability. Drawing machine operations were geometrical, and by feedback, their actions were applied to innovative machine forms in the real world, famously for example in Watt's use of the pantographic principle in his parallel motion mechanism

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[27] Ruled lines and elegant rainbow-coloured buttons came first, diffraction gratings, following the work of Fraunhofer in the 1820s, came later; see P. Grodzinski, 'A Ruling Engine Used by Sir John Barton—and Its Products,' *Transactions of the Newcomen Society* Volume XXVI, 1947, pp. 79-88; for accurate division, see the primary sources already cited in this article, and also R.C. Brooks, 'Towards the Perfect Screw Thread: The making of Precision Screws in the 17th-19th Centuries,' *Transactions of the Newcomen Society* Volume 64, 1992, pp. 101-119, Holtzapffel 1842-84.

[28] W.J. Ashworth, 'The calculating eye,' *British Journal for the History of Science* 27, 1994, pp. 409-41; S. Schaffer, 'Metrology, Metrication and Victorian Values' in B. Lightman, ed., *Victorian Science in Context*, Chicago: University of Chicago Press, 1997, pp. 438.

governing the upstroke of the piston in the double acting steam cylinder[29]. Designing machines and designing drawing machines went together; the planing machine devised by Roberts uses a very similar forward motion mechanism to the ruling machine that produced engraved lines. Collaborative working towards the production of images, via machines, draughtsmen, and engravers can also appear as a utopian assertion of industrial enlightenment and cooperation[30]. In the communications to the *Transactions* of the Society of Arts, inventor, draughtsman and engraver appeared to be equal in this self-styled forum of the useful arts where roles were interchangeable[31]

On the other, untidy side of this topic, looking at the material techniques and skills involved in the production of machine drawings, or thinking about and handling the instruments themselves, reveals some of the inconsistencies in this episode of competitive invention and prompts useful questions about the self-fashioning of engineers through apparently frivolous visual diversion. Handling and seeking out these machines can be time consuming. One has to negotiate spaces within the schedules of busy museum curators, and they in turn have to negotiate the annoying frustrations of guarding their massive dusty collections with constant funding anxieties. Their collections are perhaps not fully catalogued, and even if they are, objects still get constantly shunted around as categories or storage priorities change. But while the inertia of old objects might be a frustration, the peculiar time-zone inside the archive is also a blessing for the researcher. In writing this article, I am grateful to have had access to the collections of the National Museum of Scotland, in Edinburgh, founded as the Industrial Museum of Scotland in

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[29] Marsden 2002: 117-120 In relation to the 'problem' of not being able to create a true straight line, noted by Kempe (1877) or Bryant and Sangwin (2008), this is a good example of how a provisional and partial solution was seen to be perfectly satisfactory in its context.
[30] Stewart, Larry, 'A Meaning for Machines: Modernity, Utility, and the Eighteenth-Century British Public,' *The Journal of Modern History* 70 (2), 1998, pp. 259-94, p. 294.
[31] This charmed state, if it ever existed, did not remain as instrument makers for example became increasingly excluded from the scientific community in the 1820s and the internal power relations of large engineering concerns developed. See W.T Ginn, 'Philosophers and Artisans: The Relationship between Men of Science and Instrument Makers in London 1820-1860,' Unpublished PhD dissertation, University of Kent, Canterbury UK, 1991.

1857, and specifically conceived as 'a castle stored with the ammunition and weapons of commercial warfare.'[32] George Wilson, the first Director, valued his stores of drawing equipment. To him, all kinds of drawing instruments, from lowly pens, pencils and brushes through to untested newly invented devices were important weapons in the armoury of 'Dynamical Industrial Art.'[33] Handling some of these machines shows just how unhandy they were. For example, amongst other items in the collection we encounter the Diagraphe by the French inventor and engraver Charles Gavard[34]. This is very fiddly to assemble, with its tiny pulleys and string-driven mechanisms, not unlike threading a sewing machine. Gavard's machine is worthwhile examining in use, because it features in Martin Kemp's *The Science of Art* (1990), but only in a somewhat frictionless way where it is used to support a narrative of a progressive science of optical enquiry. Kemp's focus on the history of ideas, with images used to illustrate this narrative, obscures the reality of this uncomfortable operation[35]. The little supporting wheels, which supposedly give smooth drawing action in any direction, jam and jerk just like their large counterparts on the base of supermarket trolleys. No wonder, as David Napier observed, that draughtsmen would use any shift to copy drawings without having to resort to machines like this[36].

The relentless geometrical perfection of the discourses of the drawing machines in print are far from the obdurate material realities of their operations in the actual world. The conceptual development of drawing machines represents a continuation of the simple procedures of ruler and compass; that is, they repeat the technologies that engineers applied to themselves. Drawing with these tools is to execute a repeatable action,

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[32] G.Wilson, *The Industrial Museum of Scotland in Its Relation to Commercial Enterprise, A Lecture Delivered at the Request of the Company of Merchants of the City of Edinburgh, 4 December 1857, by George Wilson, Regius professor in the University of Edinburgh and Director of the Industrial Museum of Scotland*, Edinburgh, R & R. Clark, 1858, p. 9.

[33] Wilson, *ibid.*, p. 43.

[34] See Julie L. Mellby, Princeton University Library Graphic arts blog entry 3 February 2013, 'Gavard, diagraphe et pantographe'.

[35] Martin Kemp, *The Science of Art*, New Haven and London: Yale University Library, p. 188.

[36] David Napier, 'Universal Perspectigraph,' Society of Arts, *Transactions* 1819.

completely unlike free hand doodling. So machine drawing was a kind of teaching aid, a means of reinforcing consensus of hand-eye-brain drawing actions across a community of practice, of shaping 'perceptions as practice.'

The first stages for apprentices when working in drawing offices, in training on the job, was to copy existing drawings, executing the same actions as one's predecessors; in many contexts, geometrical drawing was instilled by drill methods[37]. Such rote learning, using guide tools to shape drawings, engineering production, and also junior engineers, bypassed the conscious centres of the brain and inscribed tacit knowledge directly in an example of the interactions of training, machine knowledge, human skills and practices[38]. While the use of technical representations to control subordinates at a distance is a well-understood concept, in fact drawing was also used as self-discipline, a means of controlling one's own expression. While drawing is often conceived as the trace of an intimate autographic gesture, engineers aimed to standardise the actions of the hand on the page. The perfect actions of machine drawings objectified those personal practices, making them self-generating and also self-evident.

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37 As in Charles Pasley's Lancastrian pedagogical methods instituted in the Engineer Department of the British Army in the 1820s; Pasley, C.W., *A Complete Course of Practical Geometry*, London: T. Egerton, Military Library, 1822.

38 Staubermann, Klaus, 'What Machine Tools Can Tell Us about Historic Skills and Knowledge,' *International Journal for the History of Engineering and Technology* 80.1 (2010): 119-132.