

Mechanical Science on the Factory Floor. The Industrial Revolution in Leeds

We think of mechanization in the late eighteenth century and we think, textiles. And as a result of the work of Musson and Robinson, Ian Inkster, Larry Stewart, David Reid, myself and others, when considering the application of mechanics, pneumatics and hydrostatics, we turn to steam applied to cotton factories or canals, or the methods used in the dredging of harbors, or to the raising of water from north country coal mines or London's Thames.¹ We also now associate all those applications of power

¹ This essay was made possible by grant #RZ-50395-05 from the NEH for collaborative research on "The First Generation of British Industrialists: Scientific Culture and Civic Life, 1780-1832." See also A. E Musson and Eric Robinson, *Science and technology in the Industrial Revolution*, Manchester, Manchester University Press, 1969; and note, "The associations of intellect and of technique were more widespread in 1851 than often thought, and acted as a solid base to the Great Exhibition of that year and to the subsequent twenty years of Golden Age machinofacture." Quoting from Ian Inkster, found in his edited volume, with Colin Griffin, et.al., *The Golden Age. Essays in British Social and Economic History, 1850-1870*, Ashgate, Aldershot, UK., 2000, p. 171. See also Margaret Jacob and Larry Stewart, *Practical Matter. Newton's Science in the Service of Industry and Empire 1687-1851*, Harvard University Press, 2004; And see L. Stewart, "A Meaning for Machines: Modernity, Utility, and the Eighteenth-Century British Public," *Journal of Modern History*, 70, June, 1998, 259-294; and Stewart, "The Boast of Matthew Boulton. Invention, innovation and projectors in the Industrial Revolution," *Economia e energia secc. XIII-XVIII*. Istituto Internazionale di Storia Economica 'F. Datini', Prato, Le Monnier, 2003, pp. 993-1010; in addition Margaret Jacob and David Reid, "Technical Knowledge and the Mental Universe of Early Cotton Manufacturers, 1800-1830," *Canadian Journal of History*, vol. 37, 2001, pp. 283-304; translated as "Culture et culture technique des premiers fabricants de coton de Manchester," *Revue d'Histoire Moderne et Contemporaine*, vol. 50, avril-juin, 2003, pp. 133-55. The argument presented here builds upon Margaret C. Jacob, *The Cultural Meaning of the Scientific Revolution*, New York, Knopf, 1988, and *Scientific Culture and the Making of the Industrial West*, New York, Oxford University Press, 1991. Endorsing and expanding on these arguments is Joel Mokyr, *The Gifts of Athena. Historical Origins of the Knowledge Economy*, Princeton, Princeton University Press, 2002, p. 66. Note in a forthcoming book, *Happy Chance*, Jack Goldstone will make a similar argument. And see Jeff Horn, "Machine-breaking in England and France during the Age of Revolution," *Labour/Le Travail* 55, Spring 2005, 143-66. and *The Path Not Taken: French Industrialization in the Age of Revolution, 1750-1830* to be published by the MIT Press in

technology with the scientific culture and experimental habits that took root in eighteenth-century Britain. That culture and the habits associated with it, in this instance as demonstrated in the factories of Leeds, form the core of this essay. There we will witness scientifically informed, factory based experimentation that transformed the woolen and linen industries. This essay offers new evidence to document the debt early industrialists owed to mechanical science and to chemistry. In their workshops where new machines and new applications of existing machines became the goal, science and technology were closely intermingled, not hierarchically but dynamically, never one and the same thing, but never far apart.² We may even describe the entrepreneurs that interest us as “hybrid savant-technologists.”³ By 1800 they and their Yorkshire factories provide yet another example of a distinctive form of material culture, sometimes called “techno-science,” present far earlier than the twentieth century associations of the term would suggest. In the critical first generation of mechanization that began in the 1780s, linen and wool manufacturers in Leeds, like their counterparts in Manchester, deployed scientific knowledge of a mechanical sort - and chemistry - to assist in the invention of

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² Rachel Laudan, “Natural Alliance or Forced Marriage? Changing Relations between the Histories of Science and Technology,” *Technology and Culture*, vol 36, no. 2, Supplement, 1995, pp. S19-22, and I would endorse her conclusion that “it is now generally accepted that there is something distinctive about technological knowledge and that it is neither irremediably tacit nor simply applied science.”

³ I am borrowing this useful phrase from Ursula Klein, “Techno-science avant la lettre,” *Perspectives on Science*, vol. 13, 2005, p. 228.

new industrial processes and forms of industrial life.⁴ Neither the technology nor the science should be imagined as reducible one to the other. Sometimes theories and calculations were invoked, other times innovative making and doing with machines consumed time and labor.⁵ Yet, distinctively, science in the form of Newtonian mechanics (as well as chemistry) received application on the factory floor, and its theories and methods, both experimental and mathematical, were applied *inter alia* to bobbins, to the weight, friction and velocity of wheels, to the gravity, elasticity and combustibility of atmospheric air.⁶

⁴ In the period from 1780 to 1800 new professions appeared for the first time in the town: cotton and fustian manufacturers, flax and worsted spinners, printers on cloth, machine makers, pattern makers and potters; see W. G. Rimmer, "The Industrial Profile of Leeds, 1740-1840," *Publications of the Thoresby Society, Miscellany*, vol. 14, part 2, 1967, p.135.

⁵Wolfgang Iffvre, "Science as Labor," *Perspectives on Science*, vol. 13, 2005, pp. 194-225, has some useful things to say about the relationship but his vision generally concerns nineteenth and twentieth century forms of techno-science. Writing in the same issue, Barry Barnes offers a useful discussion of the various meanings given to the term, "Elusive Memories of Techno-science," pp. 156-57.

⁶Marshall MSS, MS200/42, contains this note: "Leslie on Heat 8vo. 1804 communicate to air 1/750 part of the whole heat which it contains, & it will expand 1/250 part of its bulk; MS 200/57 Notebook c. 1790, f.1, Steam Engine - gives a list of engines at work in the region with all of their specifics and continued on f. 27...undated, including some engines in Manchester, f. 2 "Wrigley says there is nothing gained by a crank instead of a water wheel because of the great weight they are obliged to use at the beam end. G.W. says the Boulton and Watt's crank engines are the only ones that will produce a motion sufficiently regular for spinning." This note undated but the one below it using a different pen is 1812; f. 17 labeled Speed "the greatest speed at which they can spin cotton is 15ft a min. or 12 feet a min the day through including stoppages." f. 23 entitled Boiler, "Wrigley says it should be 4 times diameter of cylinder," dated 1804; f. 24-25 dated 1795 with these initials given "M.M. The teeth of two wheels working together must necessarily rub against one another over so much space as the difference of length of two radii meeting at the center of action of the two wheels & of two radii meeting at the thickness of a tooth from the center of action, which is the place where the teeth first begin to act. Consequently the finer the pitch & the less friction there will be upon the teeth. The best form of the teeth of wheels is that which is the strongest & at the same time admits no

The generation of the 1780s to the 1820s proved economically decisive in cities like Leeds, Manchester, and Birmingham.⁷ And by the 1790s the front-runners in the industrial race knew that what they were experiencing was unique and commented upon it extensively.⁸ Leeds, with its canal to Liverpool, stood at the center of a north

tooth to come into contact but that which is in action. The form of the tooth is therefore determined by the relative diameters of the wheels which are to work together. To find the true form of the teeth of two wheels of equal diameters draw the pitch line at half the depth of the teeth, & setting one leg of your compasses on the pitch line in the middle of one tooth draw the point of the next tooth with the other leg;" ff. 34-35 Bobbin "the relative length & diameter of a bobbin must be so proportioned that it will always be the same weight in proportion to the lever at which the thread is acting... the central force is increased as the square of the velocities, & the weight of the bobbin is increased to counteract the increased central force of the thread. In the latter case of reducing the diameter of the bobbin the stress upon the yarn would be the same as before at a velocity of 2000 revs. Because the central force & weight of bobbin would both continue the same, & the power required for giving motion to the spindle would continue the same. The central force being likewise in proportion to the quantity of matter, a bobbin of the size above described which would not spin 16 lea yarn at a greater velocity than 2000 revs. Would spin 36 lea yarn at a velocity of 3000 revs. A min. In that case the 36 lea ought to be of equal strength with the 16 lea, otherwise it would break the oftener;" f. 38 Wheels continued from f. 24 "Perhaps the best general rule for the depth of teeth is to make the depth of the acting part 3/4 of the pitch;" f. 38 on strength of wheels "Rule The square of the thickness of the tooth multiplied by its breadth will give the number of horse power that the wheel is adequate to work, if it move at a velocity of its surface of 2 1/2 [?] feet p. second of time. If the velocity is greater or less, the power is proportionate - The best breadth of a tooth is six times its thickness." See Marshall MS 200/57, ff.24-25 "Theory of Wheels"

⁷ Hannah Barker, "'Smoke cities.' northern industrial towns in late Georgian England," *Urban History*, vol. 31, 2004, pp.175-276; and for the political spokesman for this rising industrial class in Leeds see David Thornton, "Edward Baines, Senior (1774-1848), provincial journalism and political philosophy in early-nineteenth-century England," *Northern History*, xl, September 2003, 277-97.

⁸ Boulton and Watt MSS, Birmingham City Library, Series I Part 3 for extensive lists of steam engines being installed in the county of York from the 1780s onward, P6; cf Series I, Part 7, Box 322, Reel 97, #79, Boulton in Leeds writing to Watt in Birmingham, April 24, 1802, "At Manchester the increase of Mills and Dwelling Houses is beyond all former times, not less than 8 to 10 thousand in the last two years. Everywhere full employment and great plenty. Hull is increasing rapidly, where they are beginning a new Dock. At York I do not observe the smallest change."

country district experiencing rapid industrial development. The extant archives demonstrate the intellectual underpinnings of those economic developments at work among leading textile manufacturers who became central to Leeds' own, and marked, economic development. It is not the place nor time where we expect to find industrialists possessed of expanded knowledge about the physical processes fundamental to power technology. At the time neither linen nor wool cloth (unlike cotton) could be woven mechanically. Yet all the techno-scientific practices I am about to describe, facilitating the cutting edge application of power technology to manufacturing, appear at least a generation before either could be woven by power-driven machinery.⁹ Both Leeds and Manchester, in the same period, reveal a remarkably similar scientific culture. What makes their story similar is not simply the economic ingenuity evinced by manufacturers as they adapted power technology to their particular manufacturing needs, but also - and this is our focus - the technical and scientific knowledge base commonly possessed in both places and facilitating of that adaptation. In so many places textile manufacturers learned the same lessons from textbooks and lectures in natural philosophy - they learned science often cast in an applied direction - then they did something not often attempted by the scientific lecturers or writers, they approached their own technology both with new manipulations of the machines and with new conceptual apparatus. In the process they

⁹ For a good overview of the period see E.J. Connell and M. Ward, "Industrial Development, 1780-1914," in Derek Fraser, ed., *A History of Modern Leeds*, Manchester, Manchester University Press, 1980.

adapted both to the particular needs of their industry. The application of power technology, most dramatically in the form of the steam engine, advanced the factory as the setting favored by entrepreneurs to be the most accommodating place for manufacturing, soon to be imitated by all competitors.¹⁰ As the case studies mount,¹¹ the thesis of there having been a specifically *scientific* culture that expanded knowledge fundamental to power technology, receives affirmation. The mechanical knowledge was not simply grafted on to an existing set of economic conditions. It helped to shape those conditions - expensive engines made factories all the more necessary - just as the content and form of the discipline of mechanics became increasingly applied, routinized and expanded upon in factory after factory.

Current Historical and Sociological Readings of the Early Industrial Revolution

Partly in response to the work of the historians of science and technology cited above, increasingly, economic historians like Joel Mokyr and sociologists like Jack

¹⁰ Bouton and Watt Papers, Box 322 Series 1, Part 7, Reel 97, Boulton to Watt, Leeds Jan 28 1794, "From the general success of Mess. Wormald & Co's great Engine - I have no doubt of several others being wanted here if business mends on a similar plan as they are endeavouring to manufacture from the wool to finished cloth in the one building - which has not yet been done to any great extent. It caused a great bustle among the cloth makers who wish if possible to prevent it as they say merchants is becoming manufacturers. The cloth makers are a large body of men who all bring their cloth to a common hall for sale - each cloth maker has workmen of their own and they in general have the wool [?] (i.e. carded) at one place, spun at the other...it is not the working men who are so much sett against it as their masters...."

¹¹ As cited in note 1 see Jacob and Reid on Manchester.

Goldstone argue that technological innovation spurred the industrial revolution and that “the expansion of both kinds [water and steam] power was driven by exactly the same underlying culture and practice of engineering and development of mechanical power and its application to production.”¹² While Mokyr talks about how expansion in general, of useful knowledge in particular, became the key to the first Industrial Revolution - using the felicitous phrase “industrial enlightenment” to describe the new industrially relevant culture found in eighteenth century Britain¹³ - Goldstone identifies a very specific form of useful knowledge as necessary, a “greatly improved and expanded knowledge of the physical processes underlying power generation and applications, and the manipulation and creation of physical materials.”¹⁴ In other words, Goldstone designates as specifically modern, economic growth “founded on the continual and conscious application of scientific and technological progress to economic activity.”¹⁵

Similarly, historians of science like Ursula Klein argue for the relevance to industrialization of a particular configuration of science and technology. She posits an

¹² "Thoughts on the Industrial Revolution," Jack Goldstone, George Mason University, Center for Global Policy Working Paper #2, 2005, p. 7. Here he is taking issue with the work of Nicholas Crafts and C. Knick Harley in particular.

¹³ Mokyr

¹⁴ Goldstone., p. 8.

¹⁵Jack A. Goldstone, “Efflorescences and Economic Growth in World History: Rethinking the ‘Rise of the West’ and the Industrial Revolution,” *Journal of World History*, vo. 13, 2002, p. 334.

expanded understanding of techno-science which in the case of German chemistry she takes back well into the eighteenth century, even before its industrial application.¹⁶

Predictably she, and many of the historians of science cited earlier, see science as shaped by the material culture in which it lies imbedded. To the chemical workshop and the scientific societies should now be added the techno-science developed in the industrial factory of late eighteenth century Britain.

Both Mokyr and Goldstone are unimpressed by the older argument that the mechanization of cloth required not steam, but only jennies and water power. A version of that argument applied to Leeds would have it that power technology and the knowledge base used for its deployment had little to do with the wool industry until it could be applied to weaving. I too find the historiography from the 1970s unconvincing for its failure to take into account the fact that steam engines were involved in every thing from spinning and rolling to dyeing. Of course, water power remained undeniably important, particularly where a ready supply of it was available. But the water wheel could not provide the versatility of the steam engine.¹⁷ Contemporaries

¹⁶ See note two and other essays in the entire issue of *Perspectives on Science*, vol. 13, no. 4, 2005. I have hyphenated “techno-science” precisely to distinguish it from any effort to collapse the technology into the science or vice-versa.

¹⁷ Brotherton Library, University of Leeds, Special Collections, MS 18, notes made by W. Lindley on a “number of steam engines engaged in the different branches of manufacture in Leeds and its immediate vicinity,” March 1824, describes engines (37) in the production of wool cloth, flax spinning (23), stuff manufacture (2), cotton (2), dyeing (25), crushing seed (12), machine making (14), manufacturing tobacco, paper making, potteries. See also Pauline M. Litton, ed. “The Journals of Sarah Mayo Parkes, 1815 and 1818,” *Publications of the Thoresby Society*, second series, vol 13 (Miscellany), 2003, p. 3 where a water wheel is used to move a hammer in Sheffield; p. 4 to dye blue woolen cloth at Wakefield, “most of the moveable

labeled steam as the “most useful and most formidable power; where the work is of that magnitude and importance to afford the expence of erecting and working a steam engine.” If the quantity and downward force of water was not present, steam became “best and most effectual” yet enormously expensive, requiring not only fuel but a mechanic who “perfectly understands the construction of all its different parts.”¹⁸ The cutting edge entrepreneurs possessed the necessary capital for such an investment, to be sure, but they also deployed the cultural capital that came from experimenting with, and improving upon their machines, not least of which was the steam engine. Its use expanded exponentially decade by nineteenth century decade.

In one respect the older historiography did credit science with playing a role in early industrial life, if only because scientific culture gave social identity to men who largely before 1830 were outliers from the social and political elite.¹⁹ Where they

apparatus is conducted by steam;”pp. 5-6 for an extensive description of the Wormald Gott factory where the steam engine “is the great moving power in this extensive factory” that employed machines to mix the wool with oil, to spin it thread by steam driven machines (she claims that one man can do the work of 80); fulling “is very simple: the cloth is merely put into a wooden trough, to which two heavy wooden hammers are attached, that just fit into it, and each hammer works...all the vats for dyeing the cloth are boiled by steam, which save much expence and labour.” In Leeds (p. 13) she see coal carriages moved by steam; p. 16 on woolen cloth dressed by machinery moved by steam.

¹⁸ Robert Beatson, *An essay on the comparative advantages of vertical and horizontal wind-mills: containing a description of an horizontal wind-mill and water-mill, upon a new construction*; London, I. and J. Taylor; G. G. and J. Robinson; Richardson; Murray and Highley; J. Wright; E. Newbery: P. Hill, Edinburgh, 1798, pp. 3-4.

¹⁹ That could be extrapolated out of Arnold Thackray, “Natural Knowledge in Cultural Context: The Manchester Mode,” *American Historical Review*, vol. 79, 1974, pp. 672-709.

showed an interest in science, an older historiography argued, it fueled social prestige. Now we can add that it also informed practices on the shop floor. The scientific in this period largely imparted both mechanical knowledge and experimental methods, with chemistry just beginning to be important, and as we shall see, once learned by entrepreneurs, whether in wool, linen or cotton, both scientific method and knowledge, whether mechanical or chemical, made their way on to the shop floor. More was at stake than simply the status earned by establishing literary and philosophical societies or mechanics institutes, as important as they must have been for valorizing social prestige and diffusing useful knowledge.²⁰ The learning of mechanical science and its experimental protocols could transform shop floor practices.²¹

The contemporary approach being taken to the role of science in the early Industrial Revolution, as evinced by Mokyr, Goldstone, Klein, myself and others, stands in other respects in marked contrast to what had been commonplace in the literature about early industrial development well into the 1980s. Then it was fashionable to say that industrialization *tout court* had nothing to do with science, that it critically

²⁰ For a general account of the Mechanics' Institutes in Britain, see Ian Inkster, "The Social Context of an Educational Movement: A Revisionist Approach to the English Mechanics' Institutes, 1820-1850," in idem, *Scientific Culture and Urbanisation in Industrialising Britain* (Aldershot, UK: Ashgate, Variorum, 1997).

²¹ See for example, Rev. S. Vince, *A Plan of a Course of Lectures on the Principles of Natural Philosophy*, Cambridge, J. Archdeacon, 1793, p. 40, "The friction of a body does not continue the same when it has different surfaces applied to the plane on which it moves, but the smallest surface will have the least friction." The British Library copy owned by Thomas Barber in 1800 (# 1600/1154) has the following note: "some writers have asserted that friction is increased in the same body if its velocity be increased, but this is not the case, as appears from Mr. Vince's Experiments." Found in the blank sheets after p. 44.

depended upon the work of “semi-literate tinkerers.”²² It seems fair to say that now early in the twenty-first century none of the contemporary commentators who elevate technical and scientific knowledge, and focus on the interface between science and technology, would deny that skilled “tinkerers” were found in abundance in the cloth industry, before the advent of the factory, and well after it. They brought their skills to bear in a variety of vital tasks. In the production of wool cloth they could card and scribble, spin, full, weave and dye. They had considerable technical knowledge of the elaborate processes by which wool became useable cloth or worsted, or flax became linen. They could build and fix machines such as jennies. In the 1760s machine makers spoke knowledgeably about “engines,” for example, meaning a device that “worked by a screw that is... the first movement of your friseing mill and the weight lyes on the upright shaft and a new thing that rides on a pin will turn great weight with much ease.”²³ In short, oftentimes artisans and machine makers possessed mechanical knowledge about screws, levers, weights and pulleys, such as could be found during the eighteenth century in the many editions of Joseph Moxon’s *Mechanick exercises* (1683,

²² This appears widely in the older literature but can be most readily accessed in Peter Mathias, “Who Unbound Prometheus?” in Peter Mathias, ed., *Science and Society 1600-1900*, Cambridge, Cambridge University Press, 1972.

²³ John Smail, ed. *The Memorandum Books of John Brearley*, Rochester, NY, Yorkshire Archaeological Society, published by The Boydell Press, 2001, p. 13. I am grateful to this author for bringing the work to my attention and for consultation in general about industry in Leeds. See pp. 58-60 for Brearley’s knowledge of pulleys, Archimedes screws; entries here cited range from 1758-61. I also wish to thank my research assistant, Naomi Taback, who worked with me in Leeds, and the librarians in Special Collections at the Brotherton Library, Leeds University, whose speed and efficiency made this project so relatively effortless.

1693, 1703, etc.) or William Emerson's *Principles of Mechanicks* (1754, 2nd edition, 1758).²⁴

These technical men deployed a knowledge base that, in the terms used of a slightly earlier age, laid emphasis upon *praxis* or *experientia*, but not upon *episteme* or *scientia*.

A Quantitative and Qualitative Change in Scientific Knowledge

²⁴ A superb example of the kind of person I mean is found in John Smail, "Innovation and Invention in the Yorkshire Wool Textile Industry: A Miller's Tale," in Liliane Hilaire-Pérez and Anne-Françoise Garçon, *Les chemins de la nouveauté: innover, inventer au regard de l'histoire*, Paris, Éditions du CTHS, 2003, pp. 313-329. Cf. For a good description of the millwright of the mid-eighteenth century see D.T. Jenkins, *The West Riding Wool Textile Industry 1770-1835*, Pasold Research Fund Ltd., Edington, Wiltshire, 1975, pp. 101-02, quoting Fairbairn.

Contemporary historians and sociologists see more mechanical knowledge more widely available in Britain by the 1780s than elsewhere, and as being actively deployed.²⁵ We also recognize that the Newtonian synthesis qualitatively altered both celestial dynamics and terrestrial mechanics, that it unified mechanics as never before. Its principles were then explicated in textbooks that began to appear in Newton's lifetime (d. 1727) and that were remarkably similar in content from Desaguliers through to Dalton.²⁶ With increasingly successful application came the realization that deployment increased profits. In Leeds, as in Manchester, the key innovators, the pace-setters in the spinning factories of the 1790s and beyond, measured in speed, time and labor saved the value of what they knew.²⁷ Knowledge of how and why spinning machines and steam engines actually worked - of friction during rotation, of the relationship between weight and speed, of the effects of air pressure, of the centrifugal

²⁵ An argument documented in my *Scientific Culture and the Making of the Industrial West* (1997), and with Larry Stewart, *Practical Matter* (2004).

²⁶ John Desaguliers, *A Course of Experimental Philosophy*, 2nd edition, vol. 1 & 2, London, 1745; John Smeaton, "An Experimental Examination of the Quantity and Proportion of Mechanic Power Necessary to Be Employed in Giving Different Degrees of Velocity to Heavy Bodies from a State of Rest," *Philosophical Transactions of the Royal Society*, vol. 46, London, 1777; The John Rylands Library, Dalton MSS, no. 83, lecture notes dating from 1796 to 1818.

²⁷ Marshall MSS Brotherton Library, University of Leeds, Special Collections, MS 200/57, dated 1790, ff. 34-35 Bobbin "the relative length & diameter of a bobbin must be so proportioned that it will always be the same weight in proportion to the lever at which the thread is acting....The central force being likewise in proportion to the quantity of matter, a bobbin of the size above described which would not spin 16 lea yarn at a greater velocity than 2000 revs. Would spin 36 lea yarn at a velocity of 3000 revs. A min. In that case the 36 lea ought to be of equal strength with the 16 lea, otherwise it would break the oftener." F. 36 has the date of 1805. Here after cited as Marshall MSS.

principles employed by the engine's governor - was necessary before the economically risky step of deploying them could be undertaken with maximum success.²⁸ If for no other reason such knowledge insulated against fraud, and as Larry Stewart has shown, there were plenty of bogus schemes being peddled by the gullible or the shrewd. Addressing entrepreneurs, natural philosophical lecturers, from Desaguliers onward, eagerly told aspiring entrepreneurs what they needed to know: "The steam engine...cannot be understood without the previous explanation of Mechanics, Hydrostatics, and Pneumatics."²⁹ James Watt would have added the necessity of reasonably sophisticated mathematical skills such as he had acquired through his study of the Newtonian explicator of the 1720s, W. J. s'Gravesande.³⁰

²⁸A similar transition in educational level has been argued for post-Civil War American textile industry, "for the postwar world of powered manufacture...sons would need more: an understanding of mechanical principles, capacity to innovate in design, an ability to coordinate production on a grander scale." Quoted from Philip Scranton, "Learning Manufacture: Education and Shop-Floor Schooling in the Family Firm," *Technology and Culture*, vo. 27, 1986, p. 46. To see a working engine recreated with its moving parts, http://www.sciencemuseum.org.uk/exhibitions/energyhall/theme_See%20the%20engines%20at%20work.asp.

²⁹ William Turner, *A general introductory discourse, Delivered, on Tuesday, Nov. 16, 1802 on the...plan of the new institution for public lectures on Natural Philosophy*, Newcastle, [1802], p.19-20 where it is also stated that one course will comprise "the history and exhibition of the best Machines dependent on these principles." Cf. John Banks, *A Treatise on Mills*, London, 1795 and his *On the Power of Machines*, Kendal, 1803.

³⁰ Here is Watt describing the operation of one of his engines in a Cornish mine: "The consumption by cylinders of different diameters, loaded to the same number of pounds per inch, going the same number and length of strokes per minute, and constructed equally well, will be as the square of their diameters.

V. The two engines at Poldice consume 6924 bushels in 30 days; the squares of their diameters (60 and 66) are 3600 and 4356; the sum of these squares is 7956. To find the consumption of a 60 inch loaded to the average of these two, say, as 7956 (sum of the squares) is to 6924 bushels, so is 3600 (square 60) to 3131, the bushels which would be consumed in 30

days by a 60 inch cylinder, going six strokes per minute of five feet six inches long each, and loaded to 5, 4-10ths pounds per square inch". AD1583/11/66, Method of Calculating tables for Wheal Maid 63 inch Cylinder; double 9 feet or 18 feet Stroke, 1 quarto sheet, printed, late 18th century;

Method of Calculating tables for Wheal Maid 63 inch Cylinder; double 9 feet or 18 feet Stroke.

PROPOSALS to the Adventurers in. By BOULTON and WATT. To be found at

http://www.cornish-mining.org.uk/mintech/boulton_watt/volume11.htm; on Watt's scientific and technical education see Birmingham City Library, James Watt Papers, BPL, MS4/11, letters to his father, 1754-74.

Eventually by the 1830s the knowledge once promoted by natural philosophical lecturers and Newtonian textbooks would become the possession of the ubiquitous engineers who, for example in Leeds alone, by 1824 had installed 129 steam engines that, according to a contemporary witness, generated at least 2318 units of HP.³¹ Steam power could assist in spinning (but not weaving) threads and its boiler used for a stage in the dyeing process. Wool could also be dressed by steam driven machines.³² By the 1830s the weavers and fullers who aspired to become overseers of engines, or mill owners themselves, came to see that the manufacturing world of the West Riding had been transformed irreparably by a mechanical knowledge that they too needed to possess. And the new mechanics' institutes sponsored by manufacturers in nearly every town offered it to them. By that decade the publican James Kitson gives valuable evidence of what could be learned at such an institute. He described what he did not know - before he attended the Mechanics Institute in Leeds - in the following terms: "I had obtained an ordinary day school education, as a knowledge of the simple rules of arithmetic, but was completely ignorant of the most simple parts of philosophy. I knew that steam caused the steam engine to work, but I did not know how or why; I knew

³¹Leeds University, Brotherton Library, Special Collections, MS 18 "Number of steam engines engaged in the different branches of manufacture in Leeds and its immediate vicinity, from a survey of them made by W. Lindley in March 1824." In 1851 at the Great Exhibition Leeds sent 134 exhibitors, led only by Manchester with 191 and Birmingham put forward a huge 230.

³² Pauline M. Litton, ed. "The Journals of Sarah Mayo Parkes, 1815 and 1818," *Publications of the Thoresby Society*, second series, vol 13 (Miscellany), 2003, p. 16; she was particularly fascinated by steam and saw various of its applications.

that the pump caused water to rise out of a well, but I also believed that it was through the agency of suction, and I thought its power was unlimited as to extent.”³³ Through education Kitson acquired a detailed knowledge of steam and mechanics in general, and went on to become a prosperous engineer and a political reformer in the Whig tradition. The libraries and technical apparatus owned by the institutes attest to the importance awarded to learning mechanics and observing steam engines, air pumps, and by the 1830s, electrical devices.³⁴

Observing the ceaseless striving of industrialists, their contemporary critics and imitators like Kitson sensed the historical experience I seek here to recapture. In Leeds opponents of the new machinery described technology as critical, that the effort “to convert our wool into cloth...by mechanical contrivances, without the intervention of human labor” had become “a race amongst individuals.” The private greed of industrialists puts “the public good...out of the question. It is in reality, each one striving against the rest, by every possible means, to draw to himself a large proportion of the business...mechanical contrivances [are employed to accomplish this]; every one

³³ Quoted in R.J. Morris, “The rise of James Kitson: trade union and the Mechanics Institution, Leeds, 1826-1851,” *Publications of the Thoresby Society*, vol. 15, 1972, pp. 185-86. See the original in Frederic Hill, *National Education: Its present state and prospects*, London, 1836, vol. 2, p. 220-21.

³⁴ See *The Tenth Report of the Keighley Mechanics’ Institution, for the year ending April 4th, 1836 with a list of the members, a catalogue of the books and apparatus*, Keighley, R. Aken, 1836; this printed catalogue turns up in the Brotherton Library, Leeds University, Special Collections, Marriner MS 65/1. The institute was founded in 1825 and at times struggled.

endeavouring to carry them farther than another for his own particular advantage.”³⁵

By 1800, and well before, critics and entrepreneurs alike knew that more efficient machines were vital to economic success, that speed and efficiency equaled time and labor saved, profit earned. Perhaps their enemies did not know about the time the soon-to-be-wealthy technologists also spent studying the science of their day.

The Marshalls

The engines deployed most notably by the Leeds manufacturers, John Marshall in flax and Benjamin Gott in wool, operated machinery involved in nearly every other aspect of the process by which both fibers were readied for weaving, and dyed or processed, once woven. As a consequence they became the wealthiest and most influential cloth makers in the town.³⁶ What they knew about mechanization, and applied in their factories, laid down a template for others to emulate or envy.

Gradually they became civic and political leaders. By the 1830s power shifted away from the landed gentry and toward men like John Marshall who took their seats in

³⁵ [Anon} *Observations on Woollen Machinery*, Leeds, Edward Baines, 1803, p. 4; reproduced in *The Spread of Machinery. Five Pamphlets. 1793-1806*, New York, Arno Press, 1972.

³⁶ Marshall's rise is ably chronicled in W. G. Rimmer, *Marshalls of Leeds, Flax-Spinners 1788-1886*, Cambridge, Cambridge University Press, 1960; and see H. Heaton, "Benjamin Gott and the Industrial Revolution in Yorkshire," *The Economic History Review*, vol. 3, 1931-32, pp.52-53. Rimmer did not see the linkage between the natural philosophical and chemical work undertaken by Marshall and his industrial practices; he also missed the date of the critically important 1790 notebook. The electronic version of the guide simply picks up the typing error in the original.

Parliament. At his death in 1840 he was worth well over 2 million pounds. He had built multiple flax spinning mills, acquired a country estate, and fortuitously for us, saved multiple notebooks that document his participation in the scientific culture of the late eighteenth and early nineteenth centuries and its application in the mechanization of his factories.

No one carried the mechanical contrivances for their own advantage - to paraphrase their critics - further than John Marshall and Benjamin Gott. In the 1790s both installed 40 hp Boulton and Watt engines in their factories, and by 1824 Marshall's various flax mills used 5 or more engines, with the largest producing 71 hp and made by his associates, Fenton & Co. But did he understand how these engines worked? From detailed notes taken by him at the time, we know that in 1790, at a large room in Hodgson's Academy, Marshall attended a set of 15 lectures given by the itinerant scientific lecturer, Mr. Booth.³⁷ These dwelt extensively on mechanics, hydrostatics, pneumatics, chemistry, astronomy, optics, electricity, pumps, and as we know from Marshall's lecture notes, one was devoted entirely to the steam engine and other

³⁷ *The Leeds Intelligencer*, vol. 38, Number 1894, December 14, 1790, tells us that "Booth's course of lectures on natural and experimental philosophy, astronomy, chemistry...illustrated by ...apparatus, which has cost upwards of four thousand pounds...." will consist of 15 lectures at the cost of one guinea, 3 lectures a week, will begin if 40 subscribers can be found...claims his apparatus weighs up to 7 tons...he can only give one course as he has obligations in Birmingham...subscriptions can be had from him or at the bookstore of Mr Binns. There was a John Booth who also lectured in Yorkshire in this period but there is no evidence that he was a follower of Priestley nor did he announce or advertise any lectures at precisely the time when Marshall attended them.

devices.³⁸

Given the content of the chemical lectures, we can with reasonable confidence identify Mr Booth as loosely a follower of Priestley's phlogiston theory. Eric Robinson tells us that a "Mr Booth" is mentioned in a letter of 1783 to Joseph Priestley where it is said that he is seeking a recommendation. This is most probably Benjamin Booth, a scientific lecturer of the period who was involved in the circles of the 1790s associated with support for the French Revolution.³⁹ The association of radicals and scientific circles was a commonplace of the time. Of course, from 1767 to 1773 Priestley was the minister at Mill Hill Chapel in Leeds, a Unitarian establishment that the young Marshall (b. 1762) attended.⁴⁰ We can only wonder if Priestley, by 1790 relocated to Birmingham,

³⁸Marshall MSS, MS 200/42 "Philosophical Lectures and Extracts" Booth's Philosophical Lectures December 1790, Lecture 14 Miscellany "Some particulars relating to various subjects which were before omitted. Water Wheels Steam Engines."

³⁹ See Eric Robinson, "An English Jacobin: James Watt, Junior, 1769-1848," *Cambridge Historical Journal*, vol. 11, no. 3, 1955, p. 354-5, mentions that Benjamin Booth, science lecturer, was also brought up on charges of sedition as was Thomas Walker in 1792-93; Booth was later released.

⁴⁰ *Analytical Proceedings*, December 1991, vol. 28 p. 403, in article entitled "The Lunar Society and Midland Chemists" by D. Thorburn Burns, cites a letter by John Wyatt, London agent for Matthew Boulton, which notes in passing, "Mr Booth applied to Mr Parker from recommendation of Dr. Priestley." He in turn is citing an article by Eric Robinson on The Lunar Society that appeared in *Annals of Science*, 1957, vol. 13, p. 1; On the family's association with Mill Hill see W.G. Rimmer, *Marshalls of Leeds Flax Spinners 1788-1886*, Cambridge, Cambridge University Press, 1960, p. 14. For background on this Unitarian link to science see Jean Raymond and John V. Pickstone, "The Natural Sciences and the Learning of the English Unitarians," in Barbara Smith (ed.), *Truth, Liberty, Religion: Essays Celebrating Two Hundred Years of Manchester College* (Oxford: Manchester College Oxford, 1986), 127-64, pp. 134-5. On Priestley in Leeds see Robert E. Schofield, *The Enlightenment of Joseph Priestley. A Study of His Life and Work from 1733 to 1773*, University Park, The Pennsylvania State University Press, 1997, chapters 7 to 11.

might have urged Booth to tackle Leeds, or recommended him to members of his old congregation. Perhaps someone from the Gott family was also present at his lectures as the family can be associated with such interests. One John Gott (d. 1793) - possibly related - appears on a membership list of a dining club of engineers who from 1771 met around John Smeaton. Benjamin's half-brother, William, left behind a notebook filled with engineering terms and their definitions.⁴¹ The Gotts like the Watts had scientific knowledge in the family.⁴²

When advertising his upcoming lectures in the *Leeds Intelligencer* for December, 1790 Booth claimed that he had invested over £4000 in his demonstration equipment and that, in aggregate, it weighed over 7 tons.⁴³ Even allowing for exaggeration, this was a formidable arsenal that must have included air pumps and orreries, levers, pulleys, hydrometers, electrical devices, and, here I am going to hypothesize, possibly a small steam engine, or its replica. Perhaps only something quite that big would have given Mr Booth substantial tonnage, even if it was not what he was claiming. We know that such demonstration replicas existed because early in the next century instrument makers listed them in their catalogues, and two decades before Booth lectured, John

⁴¹ The Institution of Civil Engineers, London, MS Society of Civil Engineers, Treasurer's minutes and accounts, 1793-1821, meeting record of "Smeatonians;" and Brotherton Library, Leeds University, Special Collections, MS 194/14.

⁴² See my *Scientific Culture*, chapter five.

⁴³ *The Leeds Intelligencer*, vol. 38, December 14, 1790. This Mr. Booth would seem to be the same Benjamin Booth, somewhat mislabeled as "a labourer" in John Barrell, *Imagining the King's Death. Figurative Treason, Fantasies of Regicide 1793-96*, Oxford, Oxford University Press, 2000, pp. 171-79.

Smeaton informed James Watt that he had gone home and built one so as to test out Watt's claims about the energy that his engine could deliver.⁴⁴ Detailed printed lectures on mechanics in this period also employed engravings that depicted all the parts of the engine.⁴⁵ In 1799 Adam Walker's natural philosophical lectures included a list of the machinery found in his Winter Lecture Room, in Conduit Street, Hanover Square, and it included "Boulton, Blakey, Smeaton's and the common fire or steam engine." He claimed that they could not be removed because of their size, and were used to illustrate the lecture on mechanics.⁴⁶ The possibility that Booth also displayed demonstration engines takes on addition plausibility when he tells the forty subscribers he seeks to enroll (at the cost of one guinea each) that he can only give one course of

⁴⁴ Birmingham City Library, James Watt MSS, Smeaton to Boulton and Watt, 5 February 1778. Cf. "A small working model of a steam-engine all in brass...£23 2s. 0d" and "A Complete copy of Boulton & Watts most improved engine with the boiler and apparatus complete" £ 100, found in *A Catalogue of Optical, Mathematical, and Philosophical Instruments*, made and sold by W. And S. Jones, Lower Holborn, London, 1837, p. 13; in BL copy bound with C. H. Wilkinson, *An Analysis of a Course of Lectures on the Principles of Natural Philosophy*, London, 1799. There is some suggestion that as early as the 1730s Desaguliers was building models at home; see Larry Stewart, *The Rise of Public Science. Rhetoric, Technology, and Natural Philosophy in Newtonian Britain, 1660-1750*, Cambridge, UK, Cambridge University Press, 1992, p. 229.

⁴⁵ Thomas Young, *A Course of Lectures on Natural Philosophy and the Mechanical Arts*, London, Joseph Johnson, 1807, plate 24.

⁴⁶ A. Walker, *Analysis of a Course of Lectures in Natural and Experimental Philosophy*, eleventh edition, London, William Thorne, [1799]. F. Hardie tells us that he too had apparatus at his experimental philosophic lecture room that could be seen for a shilling; F. Hardie, *Syllabus of a course of lectures...at his experimental philosophic lecture room and theatre of rational amusement, Pantheon, Oxford St., London*, London, W. Burton, [1800], statement from the title page. The advertisement on the back page for Adam Walker's lectures in March says that he will devote one lecture to hydrostatics and hydraulics with the Boulton and Watt engine figuring prominently.

lectures in Leeds because he has obligations in Birmingham.⁴⁷ Although not - as far as we know - a member of the Lunar Society, Booth would seem to belong on its fringes.

By dwelling in some detail on Booth's lectures, as revealed and filtered only through the notations made by Marshall, we can get closer to the scientific way of thinking that cloth entrepreneurs could imbibe at such lectures, as well as from reading in scientific literature, also annotated in the same note book where Marshall recorded what he heard at Booth's lectures. Before turning to Marshall's detailed discussions of the many "experiments" - to use his word - that he undertook on his factory equipment and in dyeing, experiments that began in the late 1780s and continued into the next generation of Marshalls who inherited the mills,⁴⁸ we want to know what Marshall

⁴⁷ *The Leeds Intelligencer*, vol. 38, Number 1894, December 14, 1790, "Booth's course of lectures on natural and experimental philosophy, astronomy, chemistry...illustrated by ...apparatus, which has cost upwards of four thousand pounds...." will consist of 15 lectures at the cost of one guinea, 3 lectures a week, will begin if 40 subscribers can be found... he claims his apparatus weighs up to 7 tons...he can only give one course as he has obligations in Birmingham...subscriptions can be had from him or at the bookstore of Mr Binns. The same advert a week later..."he cannot do it for less than 40 people." On Dec. 28 we are told that the lectures will commence in the ensuing week 2 nights a week in Mr Hodgson's large room at the Academy. The first week pneumatics then hydrostatics.

⁴⁸ Marshall MS 200/53 "Experiments on spinning tow from June to October 1788," number 1 to 17 no foliage; for example, "From the above experiment it appears that flax will not spin with rollers the common way because the fibers will not stick together so much as to hand forward from one roller to another especially at such distances as the length of the fiber requires them to be. It will be spun best from a sliver drawn from the heckle after the same manner as worsted if that be practicable." The trial and error work of Matthew Murray noted here throughout; MS 200/55 entitled Bleaching vol. 1 contains his notes of every major chemist of the day; Berthollet, *Encyclopedie methodique*; Ainsworth, Lavoisier, 1800 Chaptal's account of vapour bleaching, f. 2 Berthollet's method of bleaching by oxygenated muriatic acid, translated in the Repertory of Arts from the *Annales de chimie*.... "when it has spent its power, it is common muriatic acid, the coloring particles having taken away its oxygen." For the next generation see Marshall MS 200/31 (I) (someone has written that this appears to be in the hand of John Marshall) and II October 30 1825 "Proposed experiments during James's absence."

learned in those wintery afternoons or early evenings at Hodgson's Academy.

In a format typical of eighteenth-century scientific courses in the Newtonian tradition - from Hawksbee to Dalton - Booth began with the very structure and uniformity of matter.⁴⁹ Throughout I quote from Marshall's notes on the first and subsequent lectures: "On matter consisting of atoms not discernible by the eye nor glasses, not capable of being produced or annihilated...5 properties of matter considered, its extension, solidity, divisibility, capability of motion & vis inertiae."⁵⁰

Although not noted by Marshall, almost certainly at this point Booth would have gone

Notes on his reading found in MS 200/42 include notes on Scheele's Chemical Essays, p. 92; Waltin's Chemical Lectures 1804 (could be Martin's) agriculture; a note on Stonehenge as an ancient observatory; from Leslie on Heat 8 vo - 1804 "Light is heat in a state of emission." "The same portion of heat raises the temperature of ice 10 degrees, water 9, steam 572 [?]; Dr Moyle's lectures 1805 on the atmosphere, lightening, rivers, the ocean; a sections labeled geology, combustible fossils; a note stating that a grain of hydrogen explodes with a force of 500 TT ? (tons); notes labeled Leslie on Heat 8vo. 1804; then notes on various books about travel. Also present notes on an item in the Phil. Trans on geology and archaeology of Lincolnshire; notes on the sea at the equator and its elevation; South America; Coal Hutton's Theory on formation of peat, extensive notations, for example, further notes include on Bruce vol. 3, Helm's travels in south America; 1809 Barrow's voyage to China; De Luc's Elements of Geology 1809; Cuvier as discussed in the Edinburgh Review 1811.

⁴⁹ For a list of Dalton's lectures see Arnold Thackray, *John Dalton. Critical Assessments of His Life and Science*, Cambridge, MA, Harvard University Press, 1972, pp.108-12 which in 1805 were as follows: 1 & 2. On matter, motion and mechanic principles, 3. Hydrostatics, 4.and 5. Pneumatics, 6. Hydraulic and pneumatic instruments, 7. 8. & 9. Electricity and Galvinism, 10. Magnetism, 11 & 12. Optics, 13. & 14. On heat, 15. On the elements of bodies and their composition, 16. On mixed elastic fluids and the atmosphere, etc., ending with astronomy, the solar system, eclipses, laws of motion of the planets explained by the whirling table, tides, system of the universe.

⁵⁰Marshall MSS, MS 200/42, "Philosophical Lectures and Extracts, Booth's Philosophical Lectures, December 1790," from Lecture 1.

on to explicate universal gravitation and the laws of local motion. Certainly we know that “The different attractions of matter were considered the attraction of cohesion, of gravity, of electricity... & [he offered] a long dissertation with several experiments on elective attractions, the knowledge of which is of great importance to chemistry & mineralogy.”⁵¹

In the same first lecture Booth mentioned phlogiston and described an experiment “made of burning a piece of iron wire in a bottle of pure air which being lighted at one end burnt entirely away melted & dropped down reduced to a perfect calx.” Immediately its industrial application follows, “which shows the wonderful effect that would be produced by blowing pure air into furnaces instead of common air for no furnace will melt wrought iron...”⁵² In the lecture on pneumatics the weight of atmospheric air on a man [and hence on a machine] is given as the equivalent of 37 tons.⁵³ The first lecture set the pattern of all the others. Theory mixed effortlessly with the most basic applications, science with technology, with explanations of how syphons and pumps worked, including one said to have been invented by Booth. The discussion of the best method for raising water is followed immediately by Newton on the tides, “Newton attributed the tide on the opposite side of the earth from the moon to the solid part of the earth being more attracted than the water on the opposite side & being as it

⁵¹ Ibid. This manuscript is not foliated.

⁵² Ibid.

⁵³ Ibid., lecture 2.

were drawn away from it.”⁵⁴

The detailed lecture in hydraulicks discussed the commonplace errors in the construction of pumps, that is “placing the low valve too high...it ought to be placed as near as possible to the surface of the water because there the water ascending acts with the greatest velocity and force,” as well as making the windbore of a less diameter than the working bar when “they ought to be the same diameter.” Booth then gave a demonstration of his model pump that moved water by a continuous circular motion.⁵⁵

⁵⁴ Ibid., lecture 5 on hydraulicks.

⁵⁵ Ibid., Lecture 5, “3. In the clack or valve...the very best possible construction is the mitre clack— a working model of Dr. Franklin’s contrivance for drawing water by a hair rope was exhibited & proved not to answer - a model of a pump invented by Mr Booth was shewn whcih pumped the water by a continued circular motion - the piston moving in a circular pipe communicating with the well below & the reservoir above there is a value in that part of the circle which is between the ascending & descending pipe & before the piston comes at that valve it touches a catch which raises the valve into the ascending pipe, the piston passes & immediately the valve is lowered to its old place. A model of a pump which made a stroke drained water both by the piston’s ascending & descending - a model of a machine for raising a quantity of water 3 feet high by means of a small stream of water equal to 78 [?] of the water raised falling 30 feet...the piece of wood then falls to the bottom & raises a quantity of water equal to its own weight at the other end of a beam” and on the next page “Newton attributed the tide on the opposite side of the earth from the moon to the solid part of the earth being more attracted than the water on the opposite side & being as it were drawn away from it. Ferguson ascribes it to the centrifugal force arising from the earth’s moving round its common center of gravity with the moon. That center of gravity is abt 2000 miles from the surface of the earth.” In discussing the clack or valve of the pump he notes that vibration decreases velocity; best construction is a “mitred clack.”

lecture 10 pneumatick chemistry - long discussion of phlogistian theory and its errors...next paragraph “dephlogisticaled marine acid discharges all colour from vegetable substances - this is the new invention for bleaching which whitens a piece of cloth in a few hours - it is procured by putting oil of vitriol onsea salt which separates the acid of salt - then by adding some blue shale or mnganese so commonly used for cleaning we find it heavier & the air in which it was calcined diminished in quantity...vital iar & inflammable air together when deprived of a part of their fire constitute water.” In the very paragraph, “Dr Priestley discovered that when air was rendered totally unfit for animal life it was purified by plants (which were exposed to the light) which absorbed the phlogisticated part of it & rendered it pure vital air - phlogisticated air he consider

Another pump, he told his audience, could “at a stroke drain water both by the piston’s ascending and descending...the piece of wood then falls to the bottom and raises a quantity of water equal to its own weight at the other end of a beam.” On the very next page Marshall recounted Newton on the tides then noted that another scientific lecturer of the period, James Ferguson, ascribed “the centrifugal force arising from the earth’s moving round its common center of gravity with the moon. The center of gravity is about 2000 miles from the surface of the earth.” In the next breath, it would seem - or certainly in Marshall’s next sentence - we are told that with pumps vibration decreases velocity, and the best valve or clack to use is a mitred one.⁵⁶ The same forces that acted on the pump acted on the tides.

After detailed lectures on astronomy, opticks, pneumatick chemistry and electricity, mechanicks followed. As did so many of the natural philosophical lectures of the eighteenth century this lecture began with basics: the lever.

There is only one power in mechanics viz the lever -

all others are resolvable into this. The quantity of power

as the patrilum [?] or food of plants. This agreed with mr Bakewell’s plans of Dishley who finds that his grass flourished the most when flooded with pure spring water without any mixture of mud or manure of any kind. Plants therefore decompose the water, the inflammable part of which serves for their nourishment & the vital air is thrown off.” Eudiometer for ascertaining the purity of air was explained... Lectures 11 and 12 electricity “electric matter is a fluid sui generis - it follows the law of all other fluids in endeavouring to keep up an equilibrium in all its parts - all bodies more or less contain a portion of this matter & that portion may be increased or diminished.” Then Dr. Moyes on Electricity....applications are discussed and these are entirely medical; also how to deploy lightning rods to protect a house, proper distance between them

⁵⁶ Ibid., lecture 5 on hydraulicks.

gained is exactly equal to the time lost. The length of a crooked lever is to be measured by dropping a perpendicular from the fulcrum to the line of direction of the two powers - Friction is equal to the weight & velocity of the moving body, & does not at all depend upon its greater or smaller surface. This was proved by a piece of wood on an inclined plane which required the same weight to draw it up on its edge as on the flat side which had 5 times the surface. The pivots of wheels should be small because of having less velocity but long that they may not wear the steps by having too great a weight on a small surface.⁵⁷

The very next lecture, devoted entirely to water wheels and steam engines, is listed in Marshall's notes, but the details are not elaborated upon. Notes taken on a book about heat, some fifteen years later, detail Marshall's continuing interest in steam and its manipulation.⁵⁸

The time has come to pass from Marshall's rich notes on Booth's scientific lectures - rare though the survival of such notes may be - and turn to the scientific mind set that Marshall brought to his early industrial and technological activities. I am not arguing

⁵⁷ Ibid., lecture 13.

⁵⁸ Ibid., "From Leslie on Heat 8 vo -1804 Light is heat in a state of emission. The same portion of heat raises the temperature of ice 10 degrees, water 9, steam 572 [? Symbol unclear.]"

that Marshall's approach to mechanical problems derived directly or entirely from Booth. Such an argument would impoverish the multiple sources available to the John Marshalls of the 1790s: conversations with engineers (many of which he recorded),⁵⁹ consultations with fellow entrepreneurs, even competitors, the long hours spent tinkering and testing rollers, spindles, dyeing techniques - all were important. But I am arguing that scientific knowledge and methods - in both mechanics and chemistry - remarkably similar to what Mr. Booth, and numerous other natural philosophical lecturers displayed - informed the approach Marshall, and his engineer employee, Matthew Murray, took. Mechanical science and chemistry became part of the process of application and innovation in his factories, whether with regard to machines, or bleaching and dyeing techniques.

This was science on the shop floor, and without seeing its role we cannot see the distinct cultural elements that went into the early Industrial Revolution. Nowhere else in Europe, or the world, did this particularly applied version of mechanical science take hold so early and so decisively, and it contributed to making Leeds by the 1830s the foremost center for woolen cloth in the Western world. By the 1820s the city and the

⁵⁹ MS 200/57 Notebook c. 1790, opening pages list all items alphabetically folio 1 Steam Engine - gives a list of engines at work in the region with all of their specifics and the region with all of their specifics and continued on f. 27...undated, including some engines in Manchester; f. 2 Wrigley says there is nothing gained by a crank instead of a water wheel because of the great weight they are obliged to use at the beam end. G.W. says the Boulton and Watt's crank engines are the only ones that will produce a motion sufficiently regular for spinning; f. 4 water wheel dimensions of various and Wrigley's comments; f. 6 lists names of names of Mechanicks, e.g., Joshua Wrigley, erector of Steam Engine & Cotton Machinery - Man (Manchester); then spindle makers, steel burners, roller makers.

Marshall firm led the country in linen production.⁶⁰

Newtonian Bobbins

When Marshall experimented with his equipment in order to improve its efficiency he did so with mathematical precision and with reference to general laws.⁶¹ He was also a consummate technologist, intensely interested in machines employed by others or in other industries, such as those used in cotton spinning.⁶² With his own machinery friction was a matter of particular concern. This quotation from one of his experiment books dated 1795 demonstrates how calculation and generalization figured noticeably in his scientific and technological style:

The teeth of two wheels working together must
necessarily rub against one another over so much
space as the difference of length of two radii
meeting at the center of action of the two wheels
& of two radii meeting at the thickness of a

⁶⁰ Rimmer, *Marshalls of Leeds*, p. 125.

⁶¹ Marshall MS 200/57 Notebook c. 1790, f. 38 labeled Strength of wheels, “To find the strength necessary for any given power - Rule The square of the thickness of the tooth multiplied by its breadth will give the number of horse power that the wheel is adequate to work, if it move at a velocity of its surface of 2 ½ [?] feet p. second of time. If the velocity is greater or less, the power is proportionate - The best breadth of a tooth is six times its thickness.”

⁶² *Ibid.*, f. 17 labeled Speed “the greatest speed at which they can spin cotton is 15ft a min. or 12 feet a min the day through including stoppages.”

tooth from the center of action, which is the place where the teeth first begin to act. Consequently the finer the pitch & the less friction there will be upon the teeth. The best form of the teeth of wheels is that which is the strongest & at the same time admits no tooth to come into contact but that which is in action.⁶³

The form of the tooth is therefore determined by the relative diameters of the wheels which are to work together. Marshall believed that friction occurred most at the exact point where the circumference of the tooth met the wheel. He continues: "To find the true form of the teeth of two wheels of equal diameters draw the pitch line at half the depth of the teeth, & setting one leg of your compasses on the pitch line in the middle of one tooth draw the point of the next tooth with the other leg." Understanding that friction was not a result of velocity, but rather of contact points, created the possibility of its more efficient reduction. Similarly the action of the bobbins as they spun the linen was approached mechanically: "the relative length & diameter of a bobbin must be so proportioned that it will always be the same weight in proportion to the lever at which the thread is acting." In addition,

⁶³ Marshall MS 500/57, Notebook c. 1790, ff. 24-25. See similar points being made by Rev. S. Vince, *A Plan of a Course of Lectures on the Principles of Natural Philosophy*, Cambridge, J. Archdeacon, 1793, p. 40, "The friction of a body does not continue the same when it has different surfaces applied to the plane on which it moves, but the smallest surface will have the least friction." Note in one British Library copy of this book, owned in 1800 by Thomas Barber of Cambridge (call number 1600/1154), the student's ms notes read in part "Some Writers have asserted that Friction is increased in the same body if its velocity be increased, but this is not the case, as appears from Mr Vince's Experiments" found in blank sheets after p. 44.

In the first case the yarn between the flyer leg & the bobbin would have to bear a stress $2/14$ times as great as at a speed of 2000 revs & the spindle would require $2\ 1/4$ times as much power to give it motion, because the central force is increased as the square of the velocities, & the weight of the bobbin is increased to counteract the increased central force of the thread.⁶⁴

In the latter case of reducing the diameter of the bobbin the stress upon the yarn would be the same as before at a velocity of 2000 revs. Because the central force & weight of the bobbin would continue the same, “the power required for giving motion to the spindle would continue the same.”⁶⁵ This Newtonian discussion of bobbins continued, “The central force being likewise in proportion to the quantity of matter, a bobbin of the size above described which would not spin 16 lea yarn at a greater velocity than 2000 revs. Would spin 36 lea yarn at a velocity of 3000 revs. a min. In that case the 36 lea ought to be of equal strength with the 16 lea, otherwise it would break the oftener.”⁶⁶

⁶⁴ Marshall MS 200/57, ff. 34-35. Note in lectures remarkably similar to Booth’s the following appears in the first lecture: “If any two weights balance each other when hung from a straight lever, they will be to each other inversely as their distances from the fulcrum.” Found in Rev. S. Vince, *A Plan of a course of Lectures on the Principles of Natural Philosophy*, Cambridge, J. Archdeacon, 1793, p. 7. These lectures concerned in this order: Mechanics, hydrostatics, optics, magnetism, and astronomy.

⁶⁵ Vince, p. 9: “In a fixed pulley, the power is equal to the weight.”

⁶⁶ Marshall MS 200/57 Notebook, dated 1790, but notes continue, and this one on f. 36 is dated 1805.

How the techno-science worked that called for this application of Newtonian mechanics to bobbins included oftentimes the presence on the shop floor of inventors with multiple skills. In the manuscript folio about "Theory of Wheels - 1795" where the bobbin is explicated appears the initials "M.M." In precisely this period Marshall was dependent upon the many innovations that his employee, the engineer Michael Murray, effected in the weaving of linen thread. Fed up with the machines then operating throughout the north, Marshall in his experiment book dated 1788 tells us that "we gave over spinning and set Matt Murray to work on a new loom."⁶⁷ For the next five years they sought to find machines that would spin thread as fine, if not finer, than what could be done by hand. They investigated worsted and cotton factories to see what, if anything, could be borrowed from their techniques. The notes left by Marshall contain discussions of tow, slivers, rollers, and carding machines, and after three years of experiments, tell of success: "This plan answered every end we wished, the slivers was level and without patches, the fibers were taken off straight, and we thought it was carded as well as possible."⁶⁸

The Cultural Vocabulary of Early Industrialists

In comparing Marshall's manuscript notebook on Booth's natural philosophical

⁶⁷ Cited in Rimmer, Marshall, p. 29.

⁶⁸ Ibid., p. 32, from Marshall's ms notebook, "experiments." See also MS 200/53 "experiments on spinning tow from June to October 1788.

lectures and the experiment book with the initials “M.M.” next to the discussion of the central force and weight of bobbins, we begin to see a pattern. Engineers and entrepreneurs shared a vocabulary that was deeply technological just as it was scientifically informed. Theory and practice were inextricably entwined; the initials suggest that Michael Murray at the least understood, or at the most, explained this bobbin principle to Marshall. Arguably Murray was to Marshall as Watt was to Boulton, entrepreneurial engineer to mechanically literate entrepreneur. Theirs was a shared vocabulary and its dictionary was both technical and scientific.

The engineer and entrepreneur spoke a language that could lead to enormous economic success, especially, as was the case with Marshall and Murray, when only one of them, namely Marshall, controlled the capital and the profit. Yet in technical matters theirs was a partnership with Murray apparently more the engineer but also highly literate. For example, friction held one key to economic success, and when not worrying about carding and bobbins, the friction of wheels also occupied the attention of the firm. They wanted to find the best depth of the teeth that would impact the wheel with least friction and yet be deep and thick enough to offer durability. The approach was both experimental and geometrical.⁶⁹ Science taught them to generalize, to see the interconnectedness of centrifugal forces at work on the tides and on bobbins. The ability to conceptualize force, velocity and weight combined with painstaking adjustments and innovations, with trials and errors made on shop floor equipment. The

⁶⁹ See note six for the best breadth of a tooth, citing MS 200/57, f.38.

ideas were no good without developing new equipment.

In the experiment books on dyeing and bleaching the same, interactive pattern between the science and the technology holds. Consistently reference is made to the latest experimental work. Marshall took notes out of books by Lavoisier, Berthollet, Chaptal, and Ainsworth, among others. In passing Marshall applied atomic theory, noting that, when oxygenated, muriatic acid “has spent its power, it is common muriatic acid, the coloring particles having taken away its oxygen.”⁷⁰ Marshall’s notes on the *Encyclopédie methodique* suggest that he read French chemistry without the aid of a translator and that he knew the latest works nearly as soon as they appeared. And always a steady stream of chemical experiments were diligently recorded.⁷¹ There was no contradiction in the minds of Marshall and Murray about how the one could inform the other. It made perfectly good sense for Marshall to read among the cutting edge chemists, or to adapt the boiler of his steam engine to steam cloth that he was attempting to dye.⁷² It is we who have imposed contradictions, tinkerers vs real scientists, trial and error vs. serious experimentation, science vs technology. Or we have wanted to merge the one into the other, refusing to see the variety of skills at play. In

⁷⁰ Marshall MSS 200/55, f. 2. For a similar discussion of oxygenated muriatic acid see William Nicholson, *A Dictionary of Chemistry*, London, G.G. and J Robinson, 1795, p. 209 entry under bleaching of linens.

⁷¹MS 200/55, f. 21 March 1798, “we began to try experiments with the bleaching liquor ...after procedures done first by Ainsworth working on cotton.”

⁷² Marshall MSS 200/55, ff. 63-64.

the process we have missed the merger of the lofty and the mundane that lay at the heart of early industrial processes.

Once the engines had been installed and the machines made ever more efficient, less rigorous men could copy and improve. The notes taken in the experiment books of the next generation of Marshalls display the same dedication to trial and error but none of the theoretical sophistication seen in the jottings of Marshall with their bows to Murray's expertise. The sons noted how "rolling we have tried as an experiment and found its effect very similar to that of stamping...there is more expense and more waste in freeing the flax from its matter and caked character before it can be heckled. It is fair to presume that if well managed, there would also be more advantage...a third method may possibly be found in the agency of steam...steam may carry away part of the gluinous matter from the fibre...."⁷³ There is not the same record of restless examination, of interrogations of engineers about which engine, if any, will do the work, nor the references to abstract principles. They were no longer needed; the basics of the factory were established and needed now to be improved upon. Perhaps for the second generation science had become so naturalized in family and civic life that its presence of the shop floor could be assumed, or talented employees could be hired who possessed the requisite education in it.

The establishment of a cost efficient factory took years of trial and error. Early in the 1790s the Gott firm consulted with a variety of engineers on the best engine to install

⁷³ Marshall MS 200/31 (I), and (II), f. 15.

in their factory.⁷⁴ Already the leading woolen and worsted manufacturing firm, it accepted Boulton and Watt's offer to install a remarkable 40 horsepower steam engine, and Benjamin Gott, the most mechanically proficient partner in the firm, became a consultant in the region on engineering problems.⁷⁵ In an experimental notebook similar to those left behind by Marshall, Gott detailed how his factory manipulated steam engines with varying amounts of water, at varying temperatures, and discovered that "a pound of water therefore in the state of steam contains more caloric than a pound of boiling water in the proportion of 950 to 212. Q.E.D."⁷⁶ Gott also pioneered the use of steam in the process of wool dyeing.⁷⁷ As he told an inventor of a hydro-mechanical press with which Gott was less than pleased, "we look after every operation of the work ourselves, and if we had experienced any advantage from the use of your press, we should have insisted on those men working it, or we should have appointed others in

⁷⁴ Brotherton Library, Gott MSS, MS 193/2 letters from Boulton and Watt, Peter Ewart, James Lawson, John Rennie; MS 193/74-84 copies of letters from Boulton and Watt that are now housed at the Birmingham City Library and are also available on microfilm.

⁷⁵ Gott MSS 193/3 f. 98 letter of 5 May 1802, from Davison to Gott asking him if he would give him an opinion of his steam engine.

⁷⁶ Gott MSS/117 Bean Ing Mill Notebook of Prices and Processes [c. 108-125], "experiments made in the Dye house Park Mill, 9 Sept. 1800."

⁷⁷ Brotherton Library, University of Leeds, Gott MS 193/3/f. 98 letter of Davison to Gott asking him if he would go with him to give his opinion of their steam engine to Mess Goodwin... "but if you can't here are queries in writing." 1802 5 May. On the engine and its many uses for scribbling, carding, turning shafts and gearings, stones to grind dyewood see H. Heaton, "Benjamin Gott and the Industrial Revolution in Yorkshire," *The Economic History Review*, vol. 3, 1931-32, pp.52-53.

their places who would have been obedient.”⁷⁸ Indeed Gott became an expert on a hydro-mechanical press, a large and complex piece of equipment introduced late in the century, requiring an understanding of levers, weights and pulleys and used to imprint patterns on textiles.⁷⁹ He experimented to establish the relative merits of prototype machines offered by rival manufacturers of the device, and may have concluded that the device did not work as it should.⁸⁰

The prestige that could be achieved

The Gott firm and family, along with the Marshalls, also became leaders in the civic and industrial life of Leeds. Indeed Gott’s expertise was also sought out by imitators and rivals alike.⁸¹ Just like the Boultons and the Watts of Birmingham, the M’Connells and the Kennedys of Manchester, the Gotts and the Marshalls established themselves as

⁷⁸ Gott MSS 193/3 f. 97 Gott to Bramah, 29 March 1809.

⁷⁹ MS 193/ 3 f. 94. Note that tool making, unlike heat engines, water motors, bridge building, etc received little guidance from scientific principles until the 20th century; see Robert B. Gordon, “Who Turned the Mechanical Ideal into Mechanical Reality?,” *Technology and Culture*, October 1988, vol. 29, pp.744-78.

⁸⁰ Ibid., f. 97 Gott to Bramah from Leeds 29 March 1809 on his hydro-mechanical press... “We have from your letter of the 25th instant that the sale and general adoption of your patent presses have been prevented by unfavorable representations respecting the merits & utility of the one you erected for us... we must ...tell you that we look after every operation of the work ourselves, and if we had experienced any advantage from the use of your press, we should have insisted on those men working it, or we should have appointed others in their places who would have been obedient...” See H. Heaton, *op. cit.*, p. 58 who takes a dimmer view of Gott’s success in putting the machine to work.

⁸¹ Brotherton Library, University of Leeds, Gott MS 193/3/f. 98 letter of May 5, 1802 Davison to Gott asking him to go with him to form an opinion of a local steam engine “but if you can’t here are queries in writing.”

leaders (or proprietary members as they were called) of a new Philosophical and Literary Society (first chaired by Gott). They and the other seventeen proprietors subscribed ^100 for a building to house the society and put out £350 for scientific apparatus.⁸² In 1821 the opening lecture valorized science, striving and the industrial order: “the thirst for improvement gives an exaltation of character...produce[s] the works of genius and the discoveries of science...science, no longer confined to the closets of the learned, is applied to the comforts and amelioration of mankind. Its influence is strikingly apparent alike in our houses and manufactories.”⁸³

The historical sources, on this occasion left by linen and woolen manufacturers in Leeds, present science and its methods as lying at the heart of a set of values, beliefs, deployed knowledge systems, in other words, of a new culture at work at the heart of early industrialization. The argument ultimately comes down to the realization that scientific acumen was not *just* cultural capital, it was also deployed. Leadership in the industrial cities passed to firms like Marshalls and Gotts in part because their knowledge base enabled them to invent or deploy mechanical contrivances that replaced human labor, to compete aggressively and to imagine themselves as superior to the idle and landed of the countryside who still possessed access to political power.

None of these people should be imagined as provincials or self-described as

⁸² Leeds University, Brotherton Library, Special Collections, MS Dep. 1975/1/6, 7 May 1819.

⁸³ Thackrah, *An Introductory Discourse. Delivered to the Leeds Philosophical and Literary Society, April 6, 1821*, Leeds, Printed for the Philosophical and Literary Society by W. Gawtress, p. 23-24.

inferiors. Their self-confidence was fueled by their success, and in the case of the Marshall family social life included Dorothy and William Wordsworth. Mrs Marshall and Dorothy had a friendship from their school girl days and the two families visited and shared confidences in the Lake District. Never do we sense in their correspondence any sense of deference or awe on the Marshall side. Indeed one senses that the Marshalls knew that their values and learning represented the future. When Marshall ventured forth into the country - and he adored rural vistas and shimmering lakes - he lamented the backwardness of clergy and landlords alike. In Wartdale he said that, unlike his own firm that offered evening education to the children it employed, the local clergy were "too idle to put in a school when one is needed." In Swaledale he noted how the "Lords of the Manor" had failed to exploit their lead mines, "what a vast saving would the present state of knowledge in Mechanicks have made them. A steam engine that cost 600 pounds would have been put up in a few months...It is surprising that steam engines have not yet been applied to lead mines." In Whitehaven he complained how the great part of the town "pays a chief rent to Lord Lonsdale - he has some good houses here uninhabited & going to ruin."⁸⁴ In the world that John Marshall and Benjamin Gott wanted nothing and no one were meant to be idle and that included the minds of engineers and entrepreneurs. Together they and countless other early industrialists brought the new science into places never imagined by its seventeenth

⁸⁴ Marshall MSS 200/63, unfoliated. For their knowledge of the Lake District and the relationship between Jane Marshall and Dorothy Wordsworth, see Ernest de Selincourt, ed. *The Letters of William and Dorothy Wordsworth*, second edition rev by Chester L. Shaver, vol. 1.

century progenitors. They knew that in combination with technology science could make new worlds. One of them first emerged in their Leeds factories.

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