Working With Figures: Industrial Measurement as Hegemonic Discourse

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Hegemony, Gramsci tells us, begins in the factory.[1] Such hegemony does not generate spontaneously but is manufactured at the very point of production. It is consequent upon the manner in which the proximate control of productive processes is carried out and most particularly the language of process control. The second industrial revolution – the rise of science-based industry – was much more than a Kondratieff of new technologies. It was rather a vast reconstruction of capitalist production with consequences arguably as profound as the English Industrial Revolution itself.[2] The second industrial revolution shaped the contemporary world, confirming global economic patterns of development, exploitation and subordination. In advanced capitalist societies science-based production in new factories and mills determined material culture wherever the market reach of corporate enterprises could extend. Science-based production meant above all productive processes that were controlled in new ways by new people. At the heart of such control lay measurement: the instrumentation of measurement, the conceptual apparatus which embraced it, and the language used around it which together "transduce[d] the World into Number".[3]

The birth of engineering science during the first industrial revolution saw attempts to measure and quantify work, so as better to control and optimize it for maximum efficiency as defined by the owners of capital. The concept and term "horsepower" represented an attempt to ground mechanical calculation of work in the natural world but it was the machine which came to be the measure and the measurer. The machine "helped form a particular notion of intelligence [and] helped define work practices."[4] The machine claimed to embody reason when in fact it embodied capital.

Industry scientists and engineers of the second industrial revolution lived and were trained at a time when the essence of the physical sciences had come to be exact measurement. Just as the laboratory became "a factory for the production of measurements" so too the factory became a site of increasingly large numbers of laboratory-type measurements.[5] Much more than the technical happened at either end of the pyrometers, polariscopes and other panoply of devices. Such "epistemic engines", as Patrick Carroll-Burke calls them, are "active boundary object[s]".[6] Their output became the data for control decisions of the broadest type. At the heart of new styles of production were new ways of measuring and at the heart of the new metrology was a new vocabulary. Agree that an iron bar does not look cherry red but is x degrees Celsius and you have agreed not just to a temperature but to control. In this sense, the new science-based industrial metrology can be characterized as a hegemonic discourse.[7] As Simon Schaffer has noted, "[m]etrologies embody and distribute rival values...and scarcely escape the interests of...class struggle".[8]

To be sure this begs a deceptively simple question: why base process control on testing and monitoring instrumentation? Although ultimately a question of work process and work place control, the answer begins with the changing nature of markets and of industrial organization in the second industrial revolution.[9] Unprecedented levels of capital concentration, the modern corporate form of business enterprise and prevalence of national and international rather than local and regional markets are all among the salient features of the second industrial revolution. For the managers of large integrated firms, problems of marketing were inseparable from problems of production. With throughput and stock turnover essential measures of business and managerial performance production had to be not just expanded but sped up to, literally, inhuman rates. Typically, raw materials and sources of supply were heterogeneous in the extreme but requirements of marketing, including the use of brand names, necessitated output to be uniform and specified in its characteristics with great and replicable exactitude. These goals could not be met using traditional production methods but they could with the application of science-based process control. As well, the secondary organization of industry encouraged, where it did not necessitate, a high-volume exchange of technical data amongst firms seeking security of enterprise via a flight from competition. Trusts, cartels, *zaibatsu*, *Interessengemeinschaften*, as well as freight car pools, power grids, patent pooling, and cross-licensing did not function as informal agreements amongst gentlemen capitalists. They rested instead on the exchange of both economic and technical information, the latter communicated in the language of the engineers who, increasingly, managed corporate enterprises.[10] Here we see too the regulatory State acting not so much as the executive committee of the bourgeoisie but as the secretariat of a confederation of trade associations. As well, as part of its legitimating function, the State's regulation of industry – in capital's own interest and giving an illusion of democratic control – often took (and takes) the form of highly technical codes and standards.[11]

The impact of all this at the point of production was revolutionary as it involved a radical remaking of work. The Baconian programme of uniting hand and head, rooted in the early modern search for a rational technology, was repudiated.[12] Instead, as enunciated clearest by F.W. Taylor, the conception and execution of work would be *essentially* separated. They would be performed by two separate social groups: the former by middle-class engineers, the latter by working class men and women. Taylor's classic formulation of "scientific management" had mechanical engineers, clipboard and stopwatch in hand, study work processes, break them down into component parts, and reassemble them the "one best way." [13] Best of course for the employer of labour. In process industries where materials could flow under gravity or pressure process control could be built right in to plant design by chemical engineers. Here, testing and control instrumentation guided production. Scientists and engineers designed such hardware and the protocol for its use. The latter included the teaching of at least some of the language of the laboratory to the workforce of machine tenders,[14] who also retained valuable if underrecognized diagnostic skills. When fully implemented the result was a more homogenous workforce of relatively high-waged semi-skilled workers. Why high-waged? For second industrial revolution firms, capital costs (materials, inventory, physical plant, borrowing) dominated while wage expenses were minimal. Interruptions in production however were very costly. The latter stages of the second industrial revolution saw the transition from Ricardo's "iron law of wages" to efficiency-wage models.[15] Crucially, this put middle class material lifestyles and the values built into middle class material culture within the reach of a large part of the working class.

Industrial science required "the use of precise technical terms based on a complex series of measurements; these cannot be expressed in the qualitative terms of human senses".[16] This involved both conceptual changes and accompanying technical protocols to transform the intuitive and qualitative as perceived by the senses into the supposedly exact and quantitative as measured by instruments. Just on its own terms, however, the juxtaposition of instrumental objectivity versus sensory subjectivity fails. Those who are reading instruments are using their bodies to do so. In reading an instrument it is the act of the reading not just the position of a needle, a bubble or a meniscus which is important. Thus it is the culture of instrumentational reading which matters.[17] That culture required a new vocabulary.[18]

Temperature and colour are properties virtually all persons experience and indeed judge daily. Temperature is perhaps the one measurement which has a sufficiently developed historiography so as not to require further elaboration here. Lest the issue appear too straightforward, however, let us review the principles as presented in an early-twentieth-century industrial monograph on fuels. Temperature measurement relates only to the flow of heat from one body to another. A measuring device acquires heat from a hotter body or gives it up to a cooler one. A graduated scale based on fixed points measures the equilibrium. The properties for indicating temperature in a thermometric or pyrometric device can include any of the following: change of volume, vapour pressure, fusion, conduction of heat, optical or electrical phenomena, radiation.[19]

Many process decisions, including temperature dependent ones, can require a judgement as to the colour of an object. A person with normal vision can distinguish among many hues and languages have rich vocabularies for colour related phenomena.[20] However, devices and procedures of increasing sophistication found their way into industry to make this subjective judgment seem increasingly objective. By the late nineteenth century, industries such as textile dyeing used devices known as colorimeters to determine the colour value of substances. A colorimeter consisted of a divided, graduated tube, into both parts of which were placed equal weights of two colourants. The darker was diluted until equal in colour to the lighter, as judged by eye. Assuming freedom from impurity, the volume of the dilutant would be proportional to its colouring power. An alternative method used standard solutions of chemicals (bleaches) to destroy colour, though this proved unreliable.[21]

To bring some uniformity to otherwise ad hoc and individualistic laboratory trials, firms prepared and sold colour standards for use in direct visual comparisons with a test sample or by use of a colorimeter. The use of colorimeters became widespread in industries as diverse as sugar and varnish. The next generation of devices were the Tintometers. Also a binocular device, rather than adding fluid, the user examined the coloured sample in one eyepiece while in the other examining a white standard. Coloured glasses of standard depth would be interposed to the standard until it appeared to match the sample and the resultant combination, e.g. red 1.3, yellow 0.7, blue 3.0, was the numerical statement of the tint.[22] By the end of the 1920s colour judgement had become mature. Technicians could employ a standard instrument, the Saybolt Chromometer, using official methods as detailed by bodies such as the American Society for Testing and Materials and reported in government technical bulletins. That device had two columns, one graduated to fill with a sample and the other into which one or two coloured disks were inserted. The depth of column to match the disk(s) was the shade of the sample fluid.[23] Thus was created what O'Connell calls a material collective, a "communit[y] of persons and institutions mutually exchanging the same representations and material representatives for abstract scientific entities."[24] The pursuit of accuracy is of course not a natural but a sociological phenomenon.[25] No one had to use these standard methods and by no means did everyone. Even as the Chromometers marched into industrial laboratories with government approval, many laboratories continued to rely on the simplest of ad hoc measurements. Thus shades of darkness (not hue) could be judged simply by using increasingly dilute solutions of some handy substance such as caramel compared, by eye, to a sample.[26]

Terms such as specific gravity, surface tension, and viscosity were not a part of the everyday vocabulary of workers, nor are or were most people conscious of directly perceiving such qualities quotidianly. They were however well understood in the laboratory with established, though evolving, procedures for their measurement. Turn of the century industrial reference books dealt in a variety of ways with the measurement of specific gravity. An explosives manufacturing text informed its readers that the granular nature of the substance in question, pores in each grain and absorption of moisture ruled out a simple volumetric measurement of density. The solution involved attempting to fill the interstices with a substance of known specific gravity in a specialized apparatus known as a densimeter. Conversely, a handbook for oil analysis declared that specific gravity was now measured as such by the same instruments used commonly in analytic laboratories. That is, the oils industries no longer used ad hoc instruments such as the "oleometer" giving a proxy of specific gravity. To assist in the transition, the author presented a simple formula for the conversion of degrees of the oleometer to specific gravity. Such formulae or conversion tables formed a considerable part of the process of routinizing and standardizing industrial measurement and in allowing employers to jump the gap from what their workers knew to what their engineers were trying to know. Standard and codified methodologies of these sorts both simplify and order complexity and change loci of skill and control in systems of production, distribution, and consumption. They "not only ensured efficient technical operations but also instantiated a hierarchy of technical expertise in production contexts...convey[ing] a particular distribution of labor from a centralized source...to the dispersed sites of industrial production."[27]

Most authorities by this time specified the use of a hydrometer for the rapid, if rough, establishment of the specific gravity of, say, an oil, or, if greater accuracy was required, a pycnometer. In the latter, a U-shaped tube with capillary tubes at right angles to each end of the U, a substance would be introduced at one end until it reached a mark at the other and then the resultant apparatus was weighed.[28] Engineers also, in classrooms, learned what measurement error was supposed to mean. They then carried this technical result into industry, making of it a social practice.[29]

Viscosity illustrates the complexity of the conceptual as well as the hardware problems of standardizing a method of producing a quantitative measure of an intuitive but slippery quality. After first noting that viscosity is worth measuring – that it relates to some aspect of a substance affecting its use – the concept then had to be clarified. That is, viscosity of an oil had to be defined and spoken of separately from notions of oiliness, slipperiness, greasiness, thickness, runniness, or whatever. Once this was done and a method had been established for measuring this particular property, it was necessary to return to the question of whether the number produced, perhaps a dimensionless coefficient, had any meaningful relationship to what you wanted to know concerning the physical world. Thus one author's comment: "The viscosity of an oil represents the degree of non-fluidity... It is very doubtful whether the viscosity of an oil, as generally determined, does give a real estimate of its lubricating power, but it affords the only convenient method for obtaining an estimate of the lubricating volume." [30] Hardly a statement of unalloyed confidence in one's methodology. It does impress upon us the need to keep in mind what Alexandre Mallard has described as the conventional truth of precise measurement, something with both a social as well as a natural character.[31]

The methodologies adopted varied widely in sophistication. The rule-of-thumb method would simply be to shake a bottle partly filled with a sample oil and note the magnitude of the rise in bubbles afterward for qualitative, comparative purposes only. A more quantitative approach would be to use a torsion viscometer, especially if you preferred the definition of viscosity as the internal friction of the substance. This apparatus involved immersing a cylinder in a bath of oil, turning it 360° and seeing how far back it turned as read off a graduated disk. More usually, the rate of efflux from a tube of given orifice under a host of standard conditions was taken as a measure of viscosity. At the simplest a pipette and stopwatch gave a measure which could at least be used comparatively. This indeed persisted for substances like glues for which standard instruments were not suitable. By the early twentieth century, the principal viscometers had been officially adopted by leading users, giving them something like validity as standards. Such devices gave only a measure of viscosity of a substance relative to some standard substance, though engineers agreed that absolute viscosity was measurable. Around 1910 methods for expressing the results absolutely in dynes became available in industry textbooks.[32] A 1934 text on *The Testing of Bituminous Mixtures* gives a good feel for how problematic this subject remained, and also how far industry boffins had progressed from looking at bubbles. First, the author identified a set of terms including softness, hardness, viscosity, consistency, ductility and plasticity which form the physical characteristics of asphaltic materials most of interest. Each required careful definition, but viscosity underlay them all. While viscosity has an exact and absolute definition, in practice it is measured either as the "passage of a definite volume of the fluid through a narrow tube" or the "falling of a solid body through the liquid".[33] For the former this involves instruments which measure the time for a standard volume of outflow under standard conditions. However, none of the units were satisfactory. They were not comparable among instruments, nor convertible to scientific units. The problem with using a falling ball (how far in a given time does a given size ball fall) is this cannot be observed directly in an opaque fluid. To try to get around that problem engineers designed apparatuses in which a line attached to the ball went over a pulley and lifted a gauge. The resultant problem of internal friction then led to electromagnetic techniques with an auditory output to record passage of the ball. Thus listening to beat notes became a measure of the physical property of viscosity, as unintuitive a notion as can be imagined. Once again, however, we should not suppose that the most high-tech techniques swept the field. Well into the 1920s one Ford plant used a cup with a hole in the bottom and a watch for viscosity measurement. The hole would be stopped up by a finger and the substance poured in. The finger would be removed and the time of outflow gave an arbitrary number for comparison with other tests.[34]

How good is a brick? If the question is not to be left, literally, in the hands of a bricklayer, it might be reconceptualized as the question of how readily the brick abrades. Engineers could measure this by weighing bricks and abrading them under some agreed upon system, either by tossing them in a rotating device, with some scrap iron to hurry matters along, or grinding them with sand and water on a table. Then the bricks are reweighed and the weight loss noted. Once convinced that abrasion may correlate with more measurable qualities, such as water absorbency and crushing strength, engineers produced tables allowing "abrasiveness" to be read off having measured the other two. Or at least so said the author of the ponderously titled *The Science of Brickmaking.*[35]

What is plasticity and how could it be measured? The concept is elusive, perhaps for certain applications meaning something such as a tendency not to break under deformation and to retain the deformed shape. A suggested "plasticimeter" took the form of a revolving inverted cone which would be lowered into a sample. The resistance to rotation would then be considered a measure of plasticity. How susceptible is a pitch to temperature change? The answer to this question required three measurements. Fusion point and hardness on the familiar Moh scale were readily available using off-the-shelf techniques. The third was the reading from a device called a consistometer, a variation of a needle penetrometer, which measured how deeply a needle penetrated under given conditions of loading, time, and temperature. From these three could be calculated a completely arbitrary (empirical) number called a "susceptibility Factor".[36]

Dryness would seem to be an intuitively obvious concept. In the analysis of many substances, take coal for an example, one often needed to know how dry it was. Frequently this represented a crucial commercial question in inter-firm transactions as it affected the price to be paid, a buyer being unwilling to pay commodity prices for water. Buyers and sellers of coal used such terms as "wet", "as-received", "air-dry", "dry", "oven-dry", and "moisture-free", an impressionistic and qualitative vocabulary on the basis of which exact prices had to be established. Transaction costs attended this problem. This terminological difficulty preceded any dispute over a sampling and measuring protocol for the presence of moisture, the interpretation of results, their relation to other measurable factors such as ash, and the subsequent use of this information.[37]

Some measurable quantities were entirely industry-specific and required special purpose devices for their quantification. One such quality, from the pulp and paper industry, is freeness, a description of how rapidly water drains away from the pulp stock solution deposited down on the wire mesh of a paper making machine. Papermakers used such terms as "slow", "free", "wet" or "greasy" to describe their pulps. The degree of freeness depended upon the prior pulping process as controlled by skilled workers. The final properties of the paper in turn depended in part on the freeness of the pulp. Beginning in Germany in the first decade of the twentieth century, engineers began attempts to quantify freeness, trying to design a machine which would take a sample of pulp and from it produce a number which represented the magnitude of freeness of that pulp. The most successful solution came from the Canadian government's Forest Products Laboratories (FPL) in Montreal in the 1920s. The basic principle of freeness testers, simulating in a controlled way what happened on the paper machine and measuring an outflow of water, is not challenging. A reliable, easy to use mechanical design, a good draughting board exercise, was only one part of the designers' task. As well, the FPL design effort carried with it a scheme for the effective calibration of such instruments, a continuing flow of technical data about them and their adoption in North America and elsewhere by industry trade associations as recognized standard instruments.[38] With the implementation of the Canadian Standard Freeness Tester as a process control instrument, a device selling for a couple of hundred dollars generated millions in cost savings to the industry.[39] The North American pulp and paper firms, and also papermakers' unions, gave support to programmes of technical education for the industry's work force. In no small part this involved teaching workers just enough of the vocabulary of plant engineers and chemists to be able to follow their directions and to use, not their own sense and senses, but instruments like Freeness Testers. By the 1930s some textbooks used in vocational education courses defined freeness in effect as that property which is measured by a standard freeness tester, perhaps the ultimate stage in any industrial metrology.[40] It is also a good example of how metrology is autonomous of neither social nor natural forces. It is an activity carried out by metrologists with some institutional authority backing them up. Schaffer, citing Wittgenstein, reminds us that it is a linguistic activity, the key to which is the non-locality of the language.[41]

"The power of...a 'measurement is...its capacity to act across space and time – to mobilize a network of social and technical actors."[42] Nowhere is this clearer than in the case of standards, specifications, and grading. Large, multi-unit and multi-national firms were to the technologies of the second industrial revolution what the factory system was to the technologies of the first. The scale and scope of their operations necessarily transcended the boundaries of the local, including local vocabularies. But of course those local vocabularies were the vocabularies of working men and women while trans-local vocabularies whilst represented as universal were no more than the specialized argot of engineers. A traditional measure was something bargained face to face; in industrial society not so. A measure involves something in the twilight between trust and authority, disembodied and mystified – for all the claim of transparency of process.[43]

The grading of pig iron, over the span of half a century, changed from an array of local variants of by-eye judgement to largely uniform chemical specifications. By the later nineteenth century a variety of local scales prevailed in both England and the United States. So, for instance, one might have had grades numbers 1-4 foundry, as determined by "degree of greyness, texture or size of the crystalline plates, and their uniformity and luster" when a sample was broken open, a procedure termed fracture.[44] Below #4 was mottled and below it white. Also, at the high end, were Bessemer #1 and #2, a cut above the ordinary numbers 1 and 2 respectively. In the early twentieth century, especially in the United States, and especially responding to pressures from oligopsonistic users, chemical specifications came increasingly into use. A typical array of grades in the pre-World War One period included #1-3 foundry, malleable, grey forge, Bessemer, Low Phosphorous, Basic, Gilchrist, or basic Bessemer. Each had a specific range of silicon, sulphur, phosphorous, and manganese. The descriptive labels, that is the nomenclature, remained confusing. One source recognized grades #1-6, with 2 and 3 each divided into an X and plain subgrades, #4 equivalent to grey forge, #5 to mottled, and #6 to white in the old English system of grades.[45] A veritable ferric Tower of Babel! Even at the end of the war, English iron was still graded by fracture and by district. The United States had more grades and made more usual use of chemical specifications. The United States did however have several regional fracture nomenclatures; textbooks presented the chemical percentage equivalents, especially for silicon and sulphur. As late as the early 1920s, textbooks in England claimed that experienced eyes could grade by fracture and judge the iron's suitability for various purposes "with great accuracy" while admitting that chemical and physical tests were increasingly used and demanded by users of iron.[46] A 1928 United States text listed the traditional grades and appearance of fracture, labeling this old but "still used to some extent".[47] By 1933 metallurgists dismissed such practices as obsolete, although in fact the nomenclature remained in usage.[48]

This reminds us of an important point. Many physical qualities which could be tested and which industry engineers would have like to have quantified proved recalcitrant. Attempts to specify a paper sample's resistance to wear, especially if crumpled or folded repeatedly, enjoyed limited success. One approach repeatedly, by hand, crumpled up and unfolded a sample, each time examining the unfolded paper against a strong light and counting the holes made in the paper. The tester plotted holes against crumples. The author of this suggestion half-heartedly asserted that a "record of this character is more satisfactory than a general statement that the paper is weak or strong".[49] Machines were designed to fold and unfold paper, but were worked manually. The paper still had to be inspected visually after each n number of folds or the sample tested for strength in the same manner as unfolded test sheets.[50] One pre-World War One text included fifty pages on chemical methods for testing volatile oils. First, however, the author discussed the usefulness and limitations of the nose as a testing device.[51] The specifications for steel transmission towers used by

Ontario Hydro included a "Hammer Test" for galvanizing. In essence it involved hitting a sample of material with a hammer to see if the coating flaked off.[52] Sensory observation of the simplest sort continued to be recommended even in specialized texts well into the twentieth century. Gelatins could be tested in an apparatus that applied increasing weight until penetrating the surface, but the preferred method simply involved poking the sample and comparing its resistance to that of standard samples.[53] Those technical specialists who endorsed this digital approach felt they had to apologize: "It is deplorable that no mathematical attribute can be applied to a standard jelly by some simple method".[54] One post-World War One handbook offered a quite sophisticated and lengthy discussion of the chemical theory of drying, including plotting weight gains and oxygen absorption against time. In the midst of it the authors admitted, "the usual method of testing of drying power is that of the craftsman who fixes the time when the film becomes satisfactorily dry to his finger... Rough though the method is..., it is satisfactory for practical purposes *in the hand of a skilled worker*."[55] Varnish film could be tested by thumbnail and thumb pressure for "tackiness" in drying. Or a device known as a Filometer could do the same. The latter used a column of mercury and completed an electrical circuit when, under increasing pressure, the film broke. However, one technical expert insisted, "an indifferent operator with an elaborate instrument [may] give a less true opinion of a varnish film than a true expert with his thumb and thumb-nail."[56] The worker's rule of thumb it seems, could in fact outperform the engineer's black box.

A final example, the purchase and use of cement in concrete construction, illustrates a number of the issues under discussion in this paper. Right off the start, if you did not know from experience how "good" cement was, what did you even mean by that? The property of "soundness" could be defined as "that property which resists any force tending to cause disintegration or lack of permanency in the structure."[57] Another term was "volume constant" cement. While recognized as dependent upon a host of measurable factors, volume constancy was itself worth measuring as a cement could pass all other tests but be unsound. Soundness could thus be determined by direct measurement of change in volume or observation of curvature and cracking of a specimen kept in a normal environment, perhaps using heat of chemicals to accelerate changes.

At times engineers' struggles to come up with a new vocabulary for what was intuitively grasped by workers seemed to echo seventeenth- and eighteenth- century scientific debates over occult properties. The "cementitious property" of cement could be measured as the percentage of "flour" (finely ground material) present.[58] Drawing an analogy with the coal industry's purchasing on the basis of calorific value, one author urged the development of the concept of "cementitious value" as the basis for the purchase of cement. This might be taken as the fineness of the dry cement delivered to a construction site. Fineness could be measured by a simple procedure (sieving it), but setting that procedure constituted an elaborate and technically demanding exercise in standard setting, controlled by professional engineering bodies. During the construction of its own generating capacity at Niagara Falls, civil engineers for the Hydro Electric Power Commission of Ontario developed what were the most technically advanced methods for concrete testing. This involved writing their own manual for concrete testing, putting on-site field laboratories and inspectors in the plant of cement suppliers, and backing it all up with further checks as well as a research programme in the Commission's Toronto laboratory. Hydro engineer R.B. Young, principally responsible for the scheme, was explicit in his requirement that final control rest with him and his colleagues in Toronto, not with supervisors at cement plants or foremen along the Niagara River.[59] Historian Amy Slaton has shown how technical standards for reinforced concrete in construction redistributed power away from construction trades workers to laboratory engineers. Standards at the work site formed part of engineers' exercise of intellectual authority there, hand in hand with managerial authority. More generally, in industrial production "epistemological trends – such as increasing precision, quantification, or standardization – embody the social visions to which scientists and engineers...subscribe" and to which they succeeded in getting others to subscribe.[60]

Lindqvist is wrong except in the most trivial sense in calling quantification "an intrinsic component of technology".[61] He is right however in seeing that the quantification of technology required institutional control over aspects of the social as well as the material. More was involved than superficial changes in vocabulary or extending accuracy to another decimal place. The revolution in measurement typified and facilitated that great reordering of capitalist production we term the second industrial revolution as well as helping to extend its reach. In fairness, what engineers claimed the new industrial metrology could do in terms of "gains" that could be measured by certain technical and commercial criteria was in fact attained. The direct social effects of these accomplishments are one part of what made that second industrial revolution truly revolutionary. However, whatever benefits arose did not accrue equally to all social groups. Most obviously, the efficiency gains were biased in scale. That is, the cost of improved measurement technologies had to be distributed over output and borne by each unit of output. Large users thus stood in a better position to gain from these technologies. As a small part of the economies of scale, and in other ways, this story is part of the story of capital concentration and the rise of oligopolistic corporations. It is equally plain that one major group of losers included skilled workers. Their keen eyes and skilled hands, their long experience and craft traditions suffered devaluation. Even allowing that a straightforward claim of "deskilling" distorts a complex and subtle process, little doubt can remain that much control over work processes shifted away from this aristocracy of labour. On the opposite side of the coin, college-trained engineers and industrial scientists numbered among the biggest winners. While they too laboured for corporate masters and had little interest in challenging the basic assumptions of industrial capitalism, these paradigmatic members of the new middle class were both chief agents and chief beneficiaries of this revolution. Not only did they come to occupy key technical and managerial positions in the new corporations but they controlled key external institutions such as standards setting bodies, trade and technical journals, government research and technical service bureaus, which proved so indispensable to the success of private firms.[62] Conflating a social with a technical programme, they used their vocabulary to "claim authority and establish expertise bring[ing] social advantage and contribut[ing] to the larger system of power relations in the workplace".[63]

The scientification of industry could not be justified on a cost-benefit analysis alone. As well, an ideology of progress and efficiency, a commitment to rational production on the part of managers sped the adoption of the new technology.[64] Rooted ultimately in Enlightenment ideals of scientific rationality, quantified statements about the measurable came to be widely regarded in society as a whole as having an especial validity, thus implicitly privileging the actions of the measurers. Tracing the claims of Enlightenment savants for the utility of mathematics outside of the physical sciences Heilbron correctly notes that this desire to measure and quantify was a desire to impose not a natural order but a very human one.[65] This can be seen as a continuation of the long process whereby the Western scientific paradigm assisted Europe's rise to global hegemony. Wise and Smith comment that "the relation that the shift to precision measurement bears to industrialization and empire building has never been thoroughly discussed."[66] Perhaps, from Innis, we should consider how the communication of information, in this case measurement information, is biased in time or space.[67] The traditional empirical and sensory measurement of generations of skilled, experienced workers had, in this sense, a time bias. The best measurements were those which had long been done and were thus well known to practitioners. The new measuration equally had a space bias, shared openly in journals and classrooms; the best measurements were those all now agreed upon and frequently were the latest techniques. This could suggest the value of the metaphor of an empire of measurement, with its hierarchies, centres of control, and problems of stability.

Notes

[1] Antonio Gramsci, *Selections from the Prison Notebooks*, ed., and trans., Quentin Hoare and Geoffrey Nowell Smith (New York: International Publishers, 1997 [1971]), 285.
[2] An overview is given in James P. Hull, "From Rostow to Chandler to You: How Revolutionary was the Second Industrial Revolution?" *The Journal of European Economic History* 25 (Spring 1996): 191-208. Compare however Ernst Homburg, "De 'Tweede Industriele Revolutie', Een problematisch historisch concept," *Historisch tijdschrift* 8 (najaar 1986): 367-385.
[3] Patrick Carroll-Burke, "Tools, Instruments and Engines: Getting a Handle on the Specificity of Engine Science," *Social Studies of Science* 31 (August 2001):593-626.
[4] William J. Ashworth, "England and the Machinery of Reason, 1780-1830," in Iwan Rhys Morus, ed., *Bodies/Machines* (Oxford: Berg, 2002), 39-66.
[5] M. Norton Wise and Crosbie Smith, "Measurement, Work and Industry in Lord Kelvin's Britain" *Historical Studies in the Physical and Biological Sciences* (1986), 12:147-173 (cite 172).
[6] Carroll-Burke, "Tools, Instruments and Engines".
[7] Andrew Barry, "The History of Measurement and the Engineers," *British Journal of the History of Science* (1993), 26: 459-468; Stuart Bennett, "'The Industrial Instrument – Master of Industry, Servant of Management': Automatic Control in the Process Industries, 1900-1940," *Technology and Culture* (1991), 32: 69-81.
[8] Simon Schaffer, "Modernity and Metrology," in Luca Guzzetti, *Science and Power: the Historical Foundation of Research Policies in Europe* (Luxembourg: EU, 2000), 71-92.
[9] This is not to suggest that measurement issues did not arise in early modern times as mercantilist states facilitated the expansion of commercial capitalism. See Carlo Poni, "Standards, Trust and Civil Discourse: Measuring the Thickness and Quality of Silk Thread," *History of Technology* 23 (2001), 1-16.
[10] Thomas K. McCraw, ed., *Creating Modern Capitalism* (Cambridge: Harvard University Press, 1997); James P. Hull "'The Surest Augery for Ultimate Success:' The Release of Proprietary Technical Knowledge by U.S. Firms in the Early Twentieth Century," *Canadian Review of American Studies* 24 (Spring 1994), 61-86.
[11] See Christopher Armstrong and H.V. Nelles, *Monopoly's Moment* (Philadelphia: Temple University Press, 1986).
[12] Kathleen H. Ochs, "The Failed Revolution in Applied Science" Ph.D. dissertation, University of Toronto, 1981.
[13] Charles Babbage, in this regard, occupies an interesting half-way house. Like Taylor he felt that there was a "one best way" for a labourer to shovel dirt. But

like Bacon he felt that the labourer should be involved in the discovery and understanding of that way. See Ashworth, " Machinery of Reason".

[14] Shapiro, following Bruno Latour, highlights the importance of this type of engineering practice in (re)creating aspects of the world of the laboratory outside of the laboratory, or in more Latourian terms making the world safe for machines. Stuart Shapiro, "Degrees of Freedom: The Interaction of Standards of Practice and Engineering Judgment," *Science, Technology & Human Values* 22 (1997), 286-316. A useful entry into the Latour canon is Bruno Latour, *Science in Action: how to follow scientists and engineers through society* (Milton Keynes: Open University Press, 1987).

[15] Gavin Wright, "Labor History and Labor Economics," in Alexander Field, ed., *The Future of Economic History* (Boston: Kluwer-Nijhoff, 1987), 334.

[16] George Perazich et al., "Industrial Instruments and Changing Technology", WPA, National Research Project Report #M-1, 1938, reprinted in I. Bernard Cohen, ed., *Research and Industry* (New York: Arno, 1980).

[17] H. Otto Sibum, "Les gestes de la mesure. Joule, les pratiques de la brasserie et la science," *Annales: Histoire, Science Sociales* 53 (1998), 745-74; Graeme Gooday, "Spot-watching, Bodily Postures and the 'Practised Eye': the Material Practice of Instrument Reading in Late Victorian Electrical Life," in Morus, ed., *Bodies/Machines*, 165-95.

[18] Rider records the attempts of Enlightenment savants to make of language a pseudo-mathematical form of discourse, giving a spurious objectivity to this basic instrument of social relations. Robin E. Rider, "Measure of Ideas, Rule of Language: Mathematics and Language in the 18th Century," in Tore Frängsmyr et al., eds., *The Quantifying Spirit in the 18th Century* (Berkley: University of California Press, 1990), 114-140.

[19] A. Humboldt Sexton, *Fuel* (London: Blackie, 1909), 261-298.

[20] The issues relating perception, cognition, and lexical denomination are tricky, however. See C. L. Hardin and L. Maffi, eds., *Color Categories in Thought and Language* (Cambridge: Cambridge University Press, 1997).

[21] J.J. Hummel, *The Dying of Textile Fabrics* (London: Cassell, 1890).

[22] Ferdinand G. Wiechmann, *Sugar Analysis* (New York: Wiley, 1893), 25; John Geddes McIntosh, *The Manufacture of Varnishes* (London: Scott, Greenwood, 1911), 420-441; R.S. Morrell and A. de Waele, Rubber, Resins. *Paints and Varnishes* (London: Bailliere, Tindall and Cox, 1921), 110-111.

[23] Carl J. Engelder, *A Laboratory Manual of Gas. Oil and Fuel Analysis* (New York: Wiley, 1931), 136 138.

[24] Joseph O'Connell, "Metrology: The Creation of Universality by the Circulation of Particulars," *Social Studies of Science* 23 (1993), 129-73.

[25] Donald MacKenzie, *Inventing Accuracy* (Cambridge: MIT Press, 1989) offered a breakthrough discussion of this point. For a more recent discussion of the sociology of knowledge as applied to technology see MacKenzie's

Mechanizing Proof (Cambridge: MIT Press, 2001).

[26] Samuel P. Wilson, *Pyroxylin Enamels and Lacquers* (New York: Van Nostrand, 1927), 209-222.

[27] Amy Slaton and Janet Abbate, "The Hidden Lives of Standards: Technical Prescriptions and the Transformation of Work in America" in Michael Thad Allen and Gabrielle Hect, ed., *Technologies of Power* (Cambridge: MIT Press, 2001), 95-143.

[28] A.C. Wright, *The Analysis of Oils* (London: Crosby Lockwood, 1903), 38. Oscar Guttmann, *The Manufacture of Explosives* (New York: Macmillan, 1895), 285-317. The word "pycnometer" is variously spelled.

[29] Schaffer, "Modernity and Metrology".

[30] Wright, *The Analysis of Oils*, 49.

[31] Alexandre Mallard, "Compare Standardize and Settle Agreement," *Social Studies of Science* 28 (1998), 571-601.

[32] Leonard Archbutt and R. Mountford Deeley, *Lubrication and Lubricants* (London, Griffin, 1907), 143-61. R. Livingston Fernbach, *Glues and Gelatine* (New York: Van Nostrand, 1907), 20-48. Compare the first six editions (1898-1911) of the following, authored by an MIT professor: Augustus H. Gill, *A Short Hand-book of Oil Analysis* (Philadelphia: Lippincott, 1898). For a discussion of the changing epistemological relationship between a fact's "factness" and its "written-downness" see Mary Poovey, *A History of the Modern Fact* (Chicago: University of Chicago Press, 1998).

[33] Donald C. Broome, *The Testing of Bituminous Mixtures* (London: Edward Arnold, 1934), 11-35.

[34] Wilson, *Proxylin*, 209-222.

[35] George F. Harris, *The Science of Brickmaking* (London: H. Grenville Montgomery, 1897), 146-149.

[36] N.V.S. Knobbs, *Lime and Magnesia* (London: Ernest Benn, 1924), 244; H.M. Langton, *Blacks and Pitches* (London: Ernest Benn, 1925), 83-85.

[37] S.W. Parr, *The Analysis of Fuel, Gas, Water and Lubricants* (New York: McGraw-Hill, 1922), 25-29.

[38] Frederic C. Clark, "The Development of Freeness Testers," *Paper Trade Journal* 92 (1931), 42-48; J.R.A. Legendre, "Summary of Work on Standardization of Standard Freeness Testers Instruments of C.P.P.A. 1925-1931" unpublished thesis in Pulp and Paper Research Institute of Canada files.

[39] W.G. Mitchell, *A Ten Year Experiment in Cooperative Industrial Research*, McGill University Archives, Principal's Papers, RG 2, c62; Editorial "Investment Which Yield 10,000 per cent," *Pulp and Paper Magazine of Canada* 32 (1932), 229.

[40] James P. Hull, "Strictly by the book: textbooks and the control of production in the North American pulp and paper industry," *History of Education* 27 (1998), 85-95.

[41] Schaffer, "Modernity and Metrology".
[42] Andrew Barry, "The History of Measurement and the Engineers," *British Journal of the History of Science* 26 (1993), 459-468.
[43] Mackenzie, *Mechanizing Proof.*
[44] H. Bauerman, *Metallurgy of Iron* (London: Crosby Lockwood, 1890), 272.
[45] Robert Forsythe, *The Blast Furnace and the Manufacture of Pig Iron* (New York: Williams, 1913), 287; J.E. Johnson, *The Principles. Operation and Products of the Blast Furnace* (New York: McGraw-Hill, 1918), 444. Christopher Hood, *Iron and Steel* (London: Pitman, n.d. 1918?).
[46] O.F. Hudson and Guy D. Bengough, *Iron and Steel* (London: Constable, 1921), 22.
[47] H.M. Boylston, *Iron and Steel* (New York: Wiley, 1928), 117- 118.
[48] Hugh P. Tiemann, *Iron and Steel* (New York: McGraw-Hill), 1933.
[49] R.W. Sindall, *Paper Technology* (London: Griffin, 1910), 113.
[50] For a review of changing techniques in paper testing see J. Newell Stephenson, ed., *The Manufacture of Pulp and Paper* (New York: McGraw-Hill, 1922).
[51] E. Gildemeister, *The Volatile Oils* (New York: Wiley, 1913), 553-617.
[52] *General Specifications for Steel Transmission Towers S.T.-010327*, Hydro One Networks Inc., Archives, GSI Collection, Accession #91-209, Bin #3-11, Box 93.
[53] R. Livingston Fernbach, *Glues and Gelatine* (New York: Van Nostrand, 1907), 20-48
[54] William A. Rooker, *Fruit Pectin* (New York: Avi, 1928), 25-26.
[55] Morrell and. de Waele, *Rubber, Resins. Paints and Varnishes* (London: Bailliere, Tindall and Cox, 1921), 68-69. Emphasis added.
[56] McIntosh, *Varnishes*, 422.
[57] W. Purves Taylor, *Practical Cement Testing* (New York, Myron C. Clark, 1908), 156.
[58] Ibid, 157-183. Bertram Blount, *Cement* (London: Longmans, Green, 1920), 140-141.
[59] *Report on Cement and Concrete Tests and Specifications*, Hydro One Networks, Inc. Archives ORR 842.2.
[60] Amy Slaton, *Reinforced Concrete and the Modernization of American Building, 1900-1930* (Baltimore: Johns Hopkins University Press, 2001).
[61] Svante Lindqvist, "Labs in the Woods: The Quantification of Technology During the Late Enlightenment," in Frängsmyr et al., eds., *Quantifying Spirit*, 291-314.
[62] Burton Bledstein, *The Culture of Professionalism* (New York: Norton, 1976); Maury Klein, *The Flowering of the Third America* (Chicago: Ivan R. Dee, 1993); Edwin T. Layton, *The Revolt of the Engineers* (Cleveland: The Press of Case Western Reserve University, 1971).

[63] Slaton and Abbate, "Hidden Lives of Standards".
[64] Yehouda Shenhav, *Manufacturing Rationality* (Oxford: OUP, 1999).
[65] See J. L. Heilbron's "Introductory Essay" in Frängsmyr et al., eds., *Quantifying Spirit*, 1-23.
[66] Wise and Smith, "Measurement".
[67] Harold A. Innis, *The Bias of Communication* (Toronto: University of Toronto Press, 1964).