The role of metrology in mediating and mobilizing the language and culture of scientific facts

W P Fisher Jr\textsuperscript{1,2} A J Stenner\textsuperscript{3}
\textsuperscript{1} BEAR Center, Graduate School of Education, University of California, Berkeley, CA (USA)
\textsuperscript{3}MetaMetrics, Inc., Durham, NC (USA)

Abstract. The self-conscious awareness of language and its use is arguably nowhere more intense than in metrology. The careful and deliberate coordination and alignment of shared metrological frames of reference for theory, experiment, and practical application have been characteristics of scientific culture at least since the origins of the SI units in revolutionary France. Though close attention has been focused on the logical and analytical aspects of language use in science, little concern has been shown for understanding how the social and historical aspects of everyday language may have foreshadowed and influenced the development and character of metrological language, especially relative to the inevitably partial knowledge possessed by any given stakeholder participating in the scientific enterprise. Insight in this regard may be helpful in discerning how and if an analogous role for metrology might be created in psychology and the social sciences. It may be that the success of psychology as a science will depend less on taking physics as the relevant model than on attending to the interplay of concepts, models, and social organization that make any culture effective.

1. Introduction

Language plays a widely recognized and visible role in culture and cultural identities. Geographic associations—sometimes quite specific ones—can often be easily inferred from linguistic clues, such as dialects or accents. Subtle matters of decorum, economic status, and social mores, as well as more obvious connections with clothing, hair styles, and adornments, may also be closely allied with variations in language.

But where language is often used in a relatively unreflective way in everyday life, language in science and engineering is explicitly oriented toward carefully crafted precision and clarity [1]. New words for systematically implemented and detailed component processes, methods, phenomena, effects, etc, need to convey very specific meanings to be useful. Consistent and routine usage of standardized metrological terms in educational, laboratory, industrial, and other contexts inevitably contributes to the shaping of social organization and cultural identity [2-11].

Conceptual complexity has increasingly well-documented interactions with social organization, with demand for metrological uniformity in science and commerce having a long history of consequences in government, academic, research, and business institutions [6]. Recent research on the

\textsuperscript{2} To whom correspondence should be addressed.
intertwined processes of concept formation and social organization [7-11] suggests a basis for resituating scientific language, concepts, and thinking relative to their origins in everyday processes. New possibilities for informing the theory and methods of psychology and the social sciences emerge as the salience of existing work into invariance, instrument calibration and equating, and the creation of shared frames of reference becomes apparent [12-15].

2. Text and technology

Over many millennia, a wide variety of technologies, from prehistoric discoveries of fire and the wheel to contemporary telecommunications and computing devices, have made it possible for persons lacking advanced skills and resources to take advantage of difficult and complex operations that would otherwise be unavailable to them. Technologies embody concepts and things in ways that make their associations accessible to end users unable to perform or invent for themselves the operations involved in producing a desired effect. As Whitehead [16] put it in 1911,

It is a profoundly erroneous truism, repeated by all copy-books and by eminent people when they are making speeches, that we should cultivate the habit of thinking of what we are doing. The precise opposite is the case. Civilization advances by extending the number of important operations which we can perform without thinking about them. In performing this function, technique and technology show their conceptual origins in the ancient Greek term, *techne*, meaning “to make” [17-18]. Other words sharing this root include text and textile, which conceptually overlap in the way they entail related spheres of weaving, yarns, threads, spinning, etc. Though the concrete media required for written text are obvious forms of technology, spoken language’s phonemes, phonetics, syntax, semantics, etc. also exhibit the features of *techne*.

Technique and technology embody the advance work done by language in the sense of codifying elaborate routines in a compact and portable method or tool. People who learn a word in a language typically have no or very limited knowledge of the experiences that led to the formation of the relevant concept but nonetheless accept the association without wondering very much about it. Just as is the case with technologies like electrical appliances, automobiles, or computers, we are born into and enculturated within social groups with long traditions of capitalizing on the practical knowledge of language and tool use while knowing little or nothing of the technical knowledge that makes the concepts and methods involved effective. Written text is in a sense the paradigmatic definition of technology in that it is the earliest obvious example of how learning was codified in a form later generations could access, whether or not they knew anything about the origins of the concepts, tools, or methods learned.

Whenever a newly salient event in the world is noted and remarked upon, an analogous word, sound, image, or sign of some kind (a text, broadly applied) is metaphorically situated in relation to other signs within a pre-existing referential system. The text of language is a model for everything technical in the sense that semiotic associations of words-things-concepts give rise to analogous associations of tools-things-models. The making of meaning via these kinds of associations is the fundamental creative act, and sets up the process by which anything else is made. The root pattern of methodical thinking lies in the way words come into language as the medium embodying the unity of an ideal concept and something in the world.

Hence we have the Greek root of method as *meta-odos*, a following along after (*meta-*) on the path (*odos*) [19] traced by the “activity of the thing itself” that thought experiences [20]. The word “method” and the concept of methodical thinking converge here, making an explicit claim to return for evidence to ‘the things themselves’ or ‘phenomena,’ i.e., to things as they show themselves before the work of abstraction and theorizing has carved out a language of fixed essences for them removed from human praxis, history and culture [21].
When a name is given by an individual to something notable or remarkable repeatedly experienced and re-cognizable in the world, that thinking process methodically and logistically coordinates and aligns a word, a concept, and a thing. This semiotic coordination might be shared with another person, and the word, or a related sign, and its position in a larger system of shared signification may then become distributed throughout a community as a part of that society’s cultural fabric [2-11, 22-23].

If that happens, the word and its associations effectively pre-think the world for those who learn what the word means from others. Those who learn the word from others do not have to acquire enough experience with the phenomenon to conceive an idea of it, do not have to give birth to new meaning embodied in a word of their own, and do not then have to translate words across personal idioms relating the same concepts and things.

This process is implicated by Gadamer [20] when he writes of the way formal logic inevitably begins from “the logical advance work language has done for it.” The advance work performed by language pre-thinks the world for us to the point of bringing about new efficiencies in the making of meaning. The to-and-fro play of conversation relieves speakers of the burden of taking the initiative by building on pre-existing shared meanings to the point of facilitating fluid, satisfying and pleasurable shared experiences. Not only does the back-and-forth of question and answer absorb interlocutors into elucidating the object of the conversation, but this may occur to the extent that their horizons or frames of reference fuse in relation to that object. This fusion is itself the moment at which both a common language and an awareness of different perspectives are created, and mutual understanding is achieved, however provisional and circumstantial it may be.

3. Advancing civilization

The prototypical metrological processes performed in the standardizations of spoken and written language pave the way for science’s deliberately arranged shared cultural frames of reference. That is, the reasoning processes used in scientific problem solving are not qualitatively different from the reasoning processes people use in other areas of life [9]. The question that arises, then, is how civilization might be advanced via psychology and the social sciences: how might we increase the number of important operations in these areas that we can perform without thinking of them? That is, instead of taking physics as the standard of success in the conduct of science, might it not make more sense to understand the social and linguistic processes through which physics has succeeded, with the aim of extending those processes into psychology and the social sciences?

Almost all state-of-the-art measurement in education, health care, performance assessment, etc. plainly depends almost entirely on the active participation of people able to think about the important operations that must be performed. Absent skilled experts, state of the art measurement simply does not usually happen in psychology or social sciences research and practice. Even when experts are involved, the complications and expense of high quality measurement are often enough to prevent it from taking place.

Why? Might it be because, with a very limited number of exceptions [12-15, 24-28], measurement in psychology and the social sciences lacks virtually any methods and traditions concerned at all with metrological traceability? With uniform unit standards? With consensus processes for determining standard product definitions? With the power of metrology for simplifying processes, for reducing costs, for streamlining communication, and for amplifying collective intelligence? Little or no attention is being focused on metrology even in the wake of recent developments that would seem to make its relevance unavoidably evident: networked communications, item banking, instrument equating, adaptive instrument administration, and the predictive control needed for on-the-fly automated item generation [14-15, 24-28]. Inevitably, however, increasing pressure to put two and two together will be applied as the human, economic,
legal, moral, social, etc. implications of advancing psychological and social measurement technologies become apparent.

In wondering how to advance civilization by simplifying end use functions, Whitehead is suggesting a model of a different kind of person than the rational Cartesian subject usually assumed as the agent of scientific and economic activity. No one, no matter how brilliant or economically advantaged, has the time and resources to be completely informed about every important factor affecting the decisions of daily life, much less in the complex operations of science. Even the simplest communication would be prohibitively cumbersome if each person was burdened with the tasks of completely re-inventing for themselves every word in a language and always being completely logical in their decision making. If everyone had to formulate their own vocabularies, grammars, etc., and then translate between them to effect any communication at all, the flow of conversation would be so obstructed as to be changed utterly in its basic character.

Even though few speakers of a language seek out any significant degree of understanding of the origins of the alphabet, script, words, grammar, orthography, etc. comprising that language, this does not prevent proper, comprehensible usage and successful communication. The capacity of language to point at things not present and to make intended meanings comprehensible even in the absence of any overt expository skill in etymology and grammar brings efficiencies to communication that make shared knowledge possible. Explaining these efficiencies is, according to Hayek, the central question of all social sciences: How can the combination of fragments of knowledge existing in different minds bring about results which, if they were to be brought about deliberately, would require a knowledge on the part of the directing mind which no single person can possess? [29]

The continuing relevance of Hayek’s question is noted by Hancock [30], who emphasizes the ways decentralized decision-making processes enable societies to employ multiple methods for exploring alternative approaches to solving problems. Others have similarly lately remarked, quoting Hayek [29], that “the marvel of the market thus resides in ‘how little the individual participants need to know to be able to take the right action’” [31]. The qualification of “little” here is, of course, relative. Massive amounts of low quality information may never support right action, and the social investments made in creating high quality scientific information may be a major portion of the total economy [2].
Bringing technical processes and objects into everyday use thus requires the coordination and alignment of a wide variety of domains of expertise, with the added problem of making each domain’s technical aspects transparent to all of the others. Without financing, accounting, management, sales, marketing, human resources, metals mining, cable manufacturing, rubber and plastics insulators, and consumers, the electrical industry would be as nonexistent as it would be if inventors, scientists and engineers had never created electrical concepts and tools in the first place.

In the terms of contemporary social studies of science [2-11], the problem is one of translating each area of stakeholders’ perspectives on technical boundary objects into the languages of each other area of stakeholders (Fig. 1) [32-33]. Ideally, alliances advance each stakeholder group’s interests further than would otherwise be possible, but this is not, of course, always the case. In education, for instance, psychometricians, statisticians, learning theorists, curriculum designers, teachers, parents, students, testing agencies, publishers, principals, researchers, accountants, and others may be allied or alienated depending on whether they successfully define a common boundary object and translate their interests in it into terms incorporated and advanced by each other area of stakeholders. The pace and spread of innovations depends in large part on being able to express technical effects in ways that capture the imaginations and interests of stakeholders across domains enough for them to coordinate and align their processes and outcomes [32-36]. Attending to the semantic role performed by technological objects within and across stakeholder communities may provide productive new paths for research and development in psychology and the social sciences [37-38].

4. Future directions
Rephrasing the question to make the interplay of concepts and social organization plain [2-11], how can we create a world in which the facts of psychological and social measurement can survive? What kind of environment would be required to build networks in which the outside world has the same form as the instruments in the laboratory? What kinds of continuous trails can be created to tie all of the literacy measures together, all of the numeracy measures together, and all of the respective relationship quality, physical functioning, and health status measures together? Can individual differences be appropriately understood and qualified? What opportunities for such networks can be envisioned, and are there any approximations of such networks already in place in education, psychology, or the social sciences? And quite importantly, how can the interests of each group of stakeholders in a given area be satisfied and represented? Can divergent and even conflicting interests be productively mediated within and between various organizations and institutions [35-36]? Can the rules, roles, and responsibilities constituting efficient market economics [34] be brought to bear on exchanges of human, social, and natural capital value [37]? Even negative answers to these questions will give clearer assurances about viable paths for productive science and economics than could be obtained if the questions had never been raised at all.

5. References
[1] Joint Committee for Guides in Metrology 2008 International vocabulary of metrology: Basic and general concepts and associated terms, 3rd ed (Sevres, France: International Bureau of Weights and Measures)
[2] Latour B 1987 Science in action (New York: Cambridge University Press)
[3] Latour B 2005 Reassembling the social (Oxford: Oxford University Press)
[4] Mendelsohn E 1992 The social locus of scientific instruments Invisible connections: Instruments, institutions, and science ed R Bud and S E Cozzens (Bellingham, WA: SPIE Optical Engineering Press) pp 5-22
[5] O’Connell J 1993 Social Studies of Science 23 129-173
[6] Ashworth W J 2004 Science 306 1314-1317
[7] Schaffer S 1997 Metrology, metrification, and Victorian values Victorian science in context ed B Lightman (Chicago: University of Chicago Press) pp 438-474
[8] Schubert C, Sydow J, and Windeler A 2013 *Research Policy* **42** 1389-1405
[9] Nersessian N J 2012 *Mind, Culture, and Activity* **19** 222-239
[10] Hutchins E 2010 *Topics in Cognitive Science* **2** 705-715
[11] Hutchins E 2012 *Mind, Culture, and Activity* **19** 314-323
[12] Fisher W P Jr 2009 *Measurement* **42** 1278-1287
[13] Rasch G 1960 *Probabilistic models for some intelligence and attainment tests* (Reprint, with Foreword and Afterword by B. D. Wright, Chicago: University of Chicago Press, 1980) (Copenhagen, Denmark: Danmarks Paedagogiske Institut)
[14] Stenner A J, Fisher W P Jr, Stone M H and Burdick D S 2013 *Frontiers in Psychology: Quantitative Psychology and Measurement* **4** doi: 10.3389/fpsyg.2013.00536
[15] Wilson M 2005 *Constructing measures: An item response modelling approach* (Mahwah, New Jersey: Lawrence Erlbaum)
[16] Whitehead A N 1911 *An introduction to mathematics* (New York: Henry Holt and Co)
[17] Heidegger M 1977 *The question concerning technology Basic writings* ed D F Krell (New York: Harper & Row) pp. 283-317
[18] Zimmerman M E 1990 *Heidegger's confrontation with modernity: Technology, politics, art* (Bloomington, Indiana: Indiana University Press)
[19] Heidegger M 1991 *The principle of reason* (Bloomington, Indiana: Indiana University Press)
[20] Gadamer H-G 1989 *Truth and method* (New York: Crossroad)
[21] Heelan P A 1994 *Galileo, Luther, and the hermeneutics of natural science Thequestion of hermeneutics* ed T J Stapleton (Dordrecht, The Netherlands: Kluwer) pp. 363-374
[22] Black M 1962 *Models and metaphors* (Ithaca, New York: Cornell University Press)
[23] Gibbs R W Jr 2011 *Discourse Processes* **48** 529-562
[24] Stenner A J, Burdick H, Sanford E E, Burdick D S 2006 *J Appl Meas* **7** 307-322
[25] Bond T, Fox C 2007 *Applying the Rasch model* (Mahwah, New Jersey: Lawrence Erlbaum)
[26] Embretson S E 2010 *Measuring psychological constructs* (Washington, DC: American Psychological Association)
[27] Engelhard G Jr 2012 *Invariant measurement* (New York: Routledge Academic)
[28] Fisher W P Jr, Wright B D 1994 *International Journal of Educational Research* **21** 557-664
[29] Hayek F A 1948 *Individualism and economic order* (Chicago: University of Chicago Press)
[30] Hancock D J 2009 The triumphs of Mercury: Connection and control in the emerging Atlantic economy *Soundings in Atlantic history: Latent structures and intellectual currents, 1500-1830* eds B Baily, P L Denault (Cambridge, MA: Harvard University Press) pp. 112-140
[31] Tadelis S, Williamson O 2010 *Transaction cost economics* (Berkeley, CA: Haas School of Business, University of California, Berkeley http://faculty.haas.berkeley.edu/stadelis/tce_org_handbook_111410.pdf)
[32] Star S L, Griesemer J R 1989 *Social Studies of Science* **19** 387-420
[33] Fox N J 2011 *Sociology* **45** 70-85
[34] Miller P, O'Leary T 2007 *Accounting, Organizations, and Society* **32** 701-734
[35] Woolley A W, Chabris C F, Pentland A, Hashmi N, Malone T W 2010 *Science* **330** 686-688
[36] Woolley A W, Fuchs E 2011 *Organization Science* **22** 1359-1367
[37] Fisher W P Jr, Stenner A J 2011 A technology roadmap for intangible assets metrology. International Measurement Confederation (IMEKO) TC1-TC7-TC13 Joint Symposium. Jena, Germany. http://www.db-thueringen.de/servlets/DerivateServlet/ Derivate-24493/ilm1-2011imeko-018.pdf
[38] Gorur R 2013 *Critical Studies in Education* **54** 132-142