Bringing Human, Social, and Natural Capital to Life:

Practical Consequences and Opportunities

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Abstract

Capital is defined mathematically as the abstract meaning brought to life in the two phases of the development of "transferable representations," which are the legal, financial, and scientific instruments we take for granted in almost every aspect of our daily routines. The first, conceptual and gestational, and the second, parturitional and maturational, phases in the creation and development of capital are contrasted. Human, social, and natural forms of capital should be brought to life with at least the same amounts of energy and efficiency as have been invested in manufactured and liquid capital, and property. A mathematical law of living capital is stated. Two examples of well-measured human capital are offered. The paper concludes with suggestions for the ways that future research might best capitalize on the mathematical definition of capital.

The Mystery of Dead vs. Living Capital

Latour (1987, p. 223) somewhat reluctantly considers defining scientific knowledge and power as capital, in the sense of repeatedly writable, additive, divisible, and portable representations that map out the terrain of a domain well enough for those following the discoverers to find their way. The capacity to generalize knowledge mathematically across different media and markets is a primary characteristic of scientific capital.

Latour also, like Hawken, Lovins, and Lovins (1999), revives the ancient root metaphor of capital's derivation from the Latin *capitus*, head. But where Latour is interested in locating thinking in a calculating center, Hawken, et al. bring out a sense of capital as part of the natural order. The concept of capital has evolved from its early sense of head of live stock: cattle, sheep, horses, etc. We could furthermore project an even earlier historical sense of capital as naturally embodied in the herds of antelope, deer, elk, or bison that migratory hunters pursued. In both cases, given the grazing and water resources that nature supplied, the herds would replenish themselves with the passing of the seasons, giving birth to new life of their own accord.

There is a sense then in which plant and animal life profits enough from naturally available resources to sustain itself. Hunters, fishers, and farmers can similarly profit from the way they manage naturally self-restoring resources within the constraints of a sustainable ecology. Profit in this sense is less a matter of greed or mere acquisition, and more of an ability to thrive in balanced overall health.

But living capital and the sustenance of an ongoing ecologically sound profitability are not restricted to forms of capital stock that walk, swim, or fly. De Soto (2000) makes a distinction between dead and living capital that explains why capitalism thrives in some countries, but not in others. De Soto points out that the difference between successful and failing capitalist countries lies in the status of what he calls transferable representations and the way they function within networks of legal and financial institutions. Transferable representations are nothing but the legally recognized and fungible titles, deeds, and other financial instruments that make it possible for the wealth locked up in land, buildings, and equipment to be made exchangeable for other forms of wealth. Titles, deeds, and the infrastructure they function within are, then, what comprise the difference between dead and living capital. Recognizing this, various organizations and governments globally are actively engaged in creating the networks of transferable representations needed to bring capital to life (IMF Staff, 2002).

In the Western capitalist economies of North America, Europe, Australia, and Japan, property can be divided into shares and sold, or accumulated across properties into an expression of total wealth and leveraged as collateral for further investment, all with no need to modify the property itself in any way. De Soto's point is that this is not so in the Third World and former communist countries, where it commonly takes years of full time work to obtain legal title, and then similar degrees of effort to maintain it. The process requires so much labor that few have the endurance or resources to complete it.

In the same way that the mass migration of settlers to the American West forced the resolution of conflicting property claims in the nineteenth century via the Preemption Act, so, too, are the contemporary mass migrations of rural people to megacities around the globe forcing the creation of a new way of legitimating property ownership. DeSoto's research shows that Third World and former communist countries harbor trillions of dollars of unleverageable dead capital. Individual countries have more wealth tied up as dead capital locked in their impoverished citizens' homes than in their entire stock markets and GDPs.

De Soto (2000, pp. 42-3) observes that capital is an inherently metaphysical concept, meaning that it exists in a purely abstract form infusing presuppositions in ways that are not usually explicit or testable. One cannot point at a definitive example of what capital is. Any instance of liquid or manufactured capital is, by definition, exchangeable with and replaceable by any other instance.

But dead capital can be clearly and decisively distinguished from living capital. Living capital is represented by a title or deed legally sanctioned by society as a generally accepted demonstration of ownership. Capital is dead, or, better, not yet brought to life, when its general value (any value it may have beyond its utilitarian function) cannot be represented so as to be leveragable or transferable across time, space, applications, enterprises, etc.

The point is this: human, social, and natural forms of capital can be thought of as being dead in the same way that Third World property is dead, in the sense of not functioning as fungible capital. We lack a means of representing the value of these forms of capital that is transferable across individuals and contexts. Latour's sense of scientific capital as mobile, additive, and divisible, and as deployed via networks of metrological (measurement science) laboratories, is especially helpful here, as it provides a root definition of what capital is. The geometry of the geodetic survey information incorporated into titles and deeds provides a fundamental insight into the qualitative mathematical metaphysics (Fisher, 2003a-c, 2004) informing capitalism and its systems of living capital. A better understanding of this metaphysics should lead to a better understanding of capital, and, perhaps, ideas as to how human, social, and natural capital can be more fully be brought to life via inscription devices that maintain a qualitative mathematical constancy across various media.

A Qualitative Mathematical Definition of Capital

Transferable representations set living capital apart from dead capital. De Soto's stresses on the metaphysical status of capital and on written, legally sanctioned, and transferable records of ownership parallels a similar emphasis on metaphysics and the repeatable interpretation and rewritability of inscribed meaning that has long been of fundamental interest to philosophers (Fisher, 2003a-c, 2004).

The distinction between a geometrical figure and its abstract meaning is held by many to mark the original philosophical insight, and is attributed to Plato (Gadamer, 1980, pp. 100-1; Heidegger, 1977). This distinction is held by some to be a virtually universally assumed, but rarely examined, metaphysical presupposition in need of much closer consideration (Burtt, 1954; Heidegger, 1967, pp. 75-6). For others, it is the only philosophical thesis of real interest (Ricoeur, 1977, p. 293; Derrida, 1982, p. 229), since it permeates all efforts at rational, critical thought (Burtt, 1954, p. 228-9; Derrida, 1978, pp. 280-1; 1989, p. 218; 2003, p. 62). Legible text, as writable meaning, has been taken as a model basis for objective inferences by physicists (Bohr, 1963, pp. 3-5; Wheeler, 1983, pp. 184-5; Heelan, 1983), philosophers (Ricoeur, 1981, p. 210; Latour, 1987; Ihde, 1991, 1998), and measurement theoreticians (Fisher, 2003c). The latter have long held that objectively meaningful measurement follows strictly only from scale invariance (the stability of numeric or geometric figures) across samples and applications (Luce, 1978; Mundy, 1986; Rasch, 1960; Roberts, 1985; Suppes, 1959; Thurstone, 1928; Wright, 1999). These requirements have a sustained history of successful application in the human and social sciences (Andersen, 1973b; Andrich, 1978, 1988; Fischer, 1973;

Fischer & Molenaar, 1995; Bond & Fox, 2007; Fisher & Wright, 1994; Smith & Smith, 2004; Wilson, 2005).

Though economists have long recognized the technical value of invariance and its associated properties in measuring capital (Usher, 1980), none have yet fully generalized the relationship between invariance and universally uniform systems of signification in the context of the contrast between dead and living capital.

Situated in this context, the resolution of the mystery of capital as a function of transferable representation becomes both more expected and more significant in its implications. For the value that is created in the birth of living capital is fundamentally mathematical, in the original philosophical sense connoting the rigorous independence of a geometrical or numerical figure from the meaning it carries. And despite the abstract ideality of its genesis, the capacity to create living capital is fundamentally substantive in its effects. De Soto (2000) distinguishes, then, between living capital and money, since "Third World and former communist nations are infamous for inflating their economies with money—while not being able to generate much capital" (p. 44). Similarly, education and health care, which might be referred to as the Third World of science, are overrun with test, assessment, and survey scores that are supposed to function as common currencies but do not actually represent anything of substance.

Scientific capital in general, then, is brought to life by means of the technology through which an effect inscribes itself in a language legible to any trained instrument operator. Titles and deeds bring capital to life by being documents written in a standardized script and incorporating geometrical surveys of property expressed in units of measurement that are recognizable, interpretable, reproducible, and applicable anywhere, any time, by any appropriately enculturated user. Such standardizations facilitate economic efficiencies by requiring fewer points of contact and less negotiation, thereby contributing to lower transaction costs (Barzel, 1982; Coase, 1990).

What is less widely appreciated is the vital importance of the way that the mathematical independence of figure and meaning, of signifier and signified, is obtained in the practical sense of measurement standards that transcend the vagaries of local variation to become mobile representations of invariantly additive and divisible amounts. Evidence of the essential significance of transparent representation to human progress in general can be found in virtually any area of endeavor. Most obviously, the emergence in the nineteenth century of widely accepted standard weights and measures provoked a plethora of scientific and economic advances commonly referred to as the Second Scientific Revolution (Brush, 1998) and the Industrial Revolution (Ashworth, 2004).

The contemporary system of property titling emerged at the same time as these revolutions, and right on the heels of the political revolutions bringing about modern democracies' constitutional and representative governments. The origins of geometry and democracy in ancient Greece are evidence of the dominance of a similar overarching paradigmatic influence. These relative simultaneities are not mere coincidences, given the pervasive influence of paradigmatic themes in historical discourse (Gadamer, 1979; Hanson, 1958; Holton, 1988; Kuhn, 1970; Wallace, 1972) and the way structurally analogous forms of order have historically been created simultaneously across social, economic, and scientific domains (Callon, 1995; Jasanoff, 2004; Latour, 2005).

Though requiring huge initial investments, the calibration of instruments indicative of amounts that can be routinely associated with numbers as a transparent currency for the exchange of scientific values, and, more specifically, with monetary values, is an investment paid back many times over. Latour (1987, p. 251) estimates that U.S. investments in metrology are three times what is spent on research and development as a whole. According to the National Institute for Standards and Technology (1996), the returns on investments made in one set of twelve areas of metrological improvement ranged from 41% to 428%.

Unfortunately, the need for scientifically rigorous measurement is often overlooked in administrative systems designed to manage the intangibles of human, social, and natural capital (Bailar, 1985). But titles, deeds, currency, receipts, credit cards, etc. nonetheless function admirably as instruments symbolically mediating virtual and actual values in a network of nodes traceable to various reference standards (alphabetic, grammatical, geometrical, scientific, financial, legal, etc.). Given 1) the fundamental value created and shared via the calibration and mobilization of these capitalist tools, and 2) a thorough understanding of how they work, the question arises as to how similar tools might be calibrated and mobilized for other forms of capital, such as the human (literacy, numeracy, health, etc.), the social (loyalty, trust, altruism, commitment, etc.), and the natural (the irreplaceable functions served by the ozone layer, trees, estuaries, watersheds, fisheries, etc.).

A Quantitative Mathematical Definition of Capital

Capital is abstract meaning brought to life in two phases characterizing the development of transferable representations, such as titles, deeds, and other legal, financial, and scientific instruments. In the first phase, something significant is conceived. That is, meaning is created experientially or experimentally by establishing the abstract existence of something capable of standing rigorously independent of the written, geometrical, metaphorical, historical, numerical, or dramatic figures carrying it (Mandel, 1978). When a figure of any kind functions as a symbol, any instance of it is then potentially interpretable as significant in a specific respect.

Once so conceived, the new form of life must be gestationally nurtured by progressively determining the limits of the environment required to sustain it. A sense of these limits is typically obtained via metrological ruggedness tests (Wernimont, 1978), wherein the conditions under which the invariant additivity, divisibility, and mobility of the numeric or other symbolic figures instrumental to capital representations come to be understood. In the human sciences, such ruggedness tests have taken the form of multiple independent experimental investigations of the fit of data to mathematical models of fundamental measurement (Andersen, 1973a; Smith, 1986, 2000). In this initial phase of capital formation, the form of life acts consistently as an agent compelling agreement among investigators as to its independent real existence (Wise, 1995).

That is, when the same construct manifests itself across different instruments intended to measure it, and across different samples hypothesized to possess it, the construct is seen to be asserting itself as a separate entity in the world in a way that fosters consensus. Though the existence of constructs is more often assumed than demonstrated, to be the objects of research, constructs plainly must be real and existing (Borsboom, Mellenbergh, & van Heerden, 2004). The value for the human sciences of Latour’s explorations of the reality of science studies lies precisely here.

For the potential capital value of an existing construct to be made actual, or, in other words, for what has been conceived and gestated to be born as an independent form of life, the second, maturational, phase of development must take place. In this phase, the symbol system (nomenclature, metric range and unit, etc.) representing the construct is mobilized via standardized inscription devices within a network or ecological niche prepared to recognize and accept that system as a common currency mediating the exchange of its particular value. This kind of cross-laboratory coordination of instruments, samples, operators, number systems, etc. is typically obtained by metrological round-robin trials (Mandel, 1978). In this second phase are determined the various conventions through which a particular form of capital will be recognized for what it is. Where the consistent display of invariant properties characterizes the first phase of capital formation, in the second phase the former nonarbitrary self-asserting agent of agreement is transformed into a product of agreement and expressed as an arbitrary convention (Wise, 1995).

A law of living capital can be stated formally in the mathematical form that virtually all the laws of physics assume, a multiplication or division of measures. Rasch (1960), for instance, found that his study of reading tests led to the discovery that the odds of a correct response from a particular student on a particular item was equal to the ratio of the student n’s overall correct response odds (B) and the item i’s overall incorrect response odds (D) (Wright & Stone, 1979):

$$(P_{ni}/(1-P_{ni})) = B_n / D_i$$

where n denotes the student and i denotes the item.[1]

[1] When the odds ratio is transformed via the natural logarithm, the resulting logit is the difference between the measured ability and the item difficulty: $\ln(P_{ni}/(1-P_{ni})) = B_n - D_i$.

Rasch (1960, pp. 110-5) observed that this law has exactly the same form as Maxwell's 1876 analysis of the concepts of acceleration, mass and force in Newton's theory of motion:

$$A_{ni} = F_n / M_i ,$$

which represents the relation of the mass M of the object i to the force F exerted by instrument n that results in the acceleration A. Rasch (1960, p. 115) concludes that

> Where this law can be applied it provides a principle of measurement on a ratio scale of both stimulus parameters and object parameters, the conceptual status of which is comparable to that of measuring mass and force. Thus, ... the reading accuracy of a child ... can be measured with the same kind of objectivity as we may tell its weight.

The law then requires a simultaneously-effected mutual convergence and separation of (1) figures serving as the media instrumental to meaningful qualitative relations and (2) observations hypothesized to represent those relations. Rasch describes how to implement what is in effect a mathematical definition of capital by making a distinction between the abstract parameters estimated (the meaning) and the concrete observations recorded as data (the written figures):

> On the basis of [one of the equations in the model] we may estimate the item parameters independently of the personal parameters, the latter having been replaced by something observable, namely, by the individual total number of correct answers. Furthermore, on the basis of [the next equation] we may estimate the personal parameters without knowing the item parameters, which have been replaced by the total number of correct answers per item. Finally, [the third

> equation] allows for checks on the model [another equation], which are independent of all the parameters, relying only on the observations (Rasch 1961, p. 325; 1960, p. 122).

To satisfy the requirements of this separability theorem, the units of the measure (e.g., hash marks on a ruler that appear evenly spaced) must consistently correspond with corresponding unit differences observed in some relevant range of objects being measured (e.g., structures extended in space), and vice versa. The convergence effected between any one instrument and any one set of things measured must then be generalizable in the sense that the same qualitative relations must be found to hold (1) when the instrument is applied to a new sample, and (2) between any other instruments of the given type and any other samples from the same population of objects. Studies of this kind of invariance are the object of metrological ruggedness tests in the natural sciences and engineering.

There are solid foundations for a new metrological science integrating the natural and social sciences. Just as Rasch (1960, pp. 110-5) linked mass, force, and acceleration with reading ability, text difficult, and comprehension rates in the context of a separability theorem, so, too, has the balance scale been taken as the basis for equilibrium models of economic relationships in the context of a parameter separation theorem (Boumans, 2001; Maas, 2001; Rubinstein, 2003). This combination of model and theorem was in fact proposed by Irving Fisher, who was a close colleague of Rasch's mentor Ragnar Frisch (Fisher, 2008). Relative to the state of the art in economics, Rasch's work remains remarkable for its compact efficiency and for its focus on instrument calibration as a means of fixing results obtaining separable parameters. In economics, in contrast, calibration is still an article of faith for future development (Boumans, 2005, p. 180).

These models and their associated data quality requirements must be posed and met in the human, social, and environmental sciences for their respective forms of capital to be brought to life. Examination, survey, and assessment questions must also be required to take up consistent and invariant orders and spacings along measurement continua in association with appropriately varying observations of human, social, or natural capital phenomena. Though such a requirement may seem too rigid an obstacle for many instruments to overcome, it is met fairly routinely in the context of probabilistic models that allow for, and estimate, small amounts of error in the calibrations and measures Andersen, 1973b; Andrich, 1978, 1988; Fischer, 1973; Fischer & Molenaar, 1995; Bond & Fox, 2007; Fisher & Wright, 1994; Smith & Smith, 2004; Wilson, 2005).

Theoretical explanations for the behaviors of items across instruments and respondent samples has advanced in the cases of a few variables to the point that the differences between predicted and observed calibrations are quite small (Carpenter, Just, & Shell, 1990; Dawson, 2002; Embretson, 1998; Green & Kluever, 1992; Massof, 2007; Stenner, Burdick, Sanford, & Burdick, 2006). The value of this achievement is not widely appreciated. Burdick, Stone, and Stenner (2006) provide a rare exposition of the equivalent mathematical structure of a law from the natural sciences and one from the human sciences. Given the role of reliably reproducible lawful phenomena in the advancement of science and the quality of life, strong theories able to guide prediction would seem foundational to an effective metrological paradigm for currently intangible forms of capital.

That is, the most flexible, valid, and reliable measurement can be obtained only when a form of capital is understood well enough that measures of it can be calibrated from theory. If we had to calibrate every lot of electrical cable, thermometers, batteries, and all other kinds of measuring devices in the course of their manufacture empirically, on the basis of actual test data, the vast majority of the consumer products we take for granted would probably be too expensive to produce. In that kind of economy, capital resources would be effectively dead because they would remain tied to the concrete particulars comprising them.

These resources in fact enrich our lives because mathematical theories make it possible to manufacture electrical cable, for instance, in a manner that requires only intermittent and limited testing of its properties as assurance that it will perform as expected. A standard length of cable manufactured of a standard composite alloy at a certain diameter will routinely resist the flow of electrical current by a standard unit. In so doing, the cable serves as a transferable representation of the Ohm, and facilitates the distribution, application, and sale of capital energy resources.

How might similar economies of living capital be created for other kinds of human, social, and natural resources, given that decades of measurement research have firmly established the validity of Rasch's (1960, p. 115) epistemological claim that data fitting his models implies that "the reading accuracy of a child…can be measured with the same kind of objectivity as we may tell its weight"? Interestingly, Rasch came to a fuller understanding of the value of parameter separation in his models as a result of a conversation with one of his teachers, the Nobel-prize winning economist, Ragnar Frisch (Andrich, 1997; Wright, 1980). Frisch's (1936) assessment of the problem of numerical indices was a significant development in efforts to address aggregation problems in the measurement of capital (Boumans, 2005; Diewert, 1980). In addition, Frisch (1930) authored a work on the necessary and sufficient conditions for meeting tests of his colleague Irving Fisher's (1930) theorem concerning the separation of price and interest parameters, or of prices and the quantity of money, in economic models (Boumans, 2005, p. 166; Fisher, 2008). Not only did Frisch win the first Nobel Prize in economics for his work in this area, Irving Fisher's work has lately been repeatedly celebrated as making multiple seminal contributions to the foundations of econometrics, such as the quantity theory of money that forms the basis of the Federal Reserve's inflation control policies (Dimand, 1997, 1998; Dimand & Geanakopolos, 2005; G. Fisher, 2005; Frisch, 1947a, 1947b). This work undoubtedly set the stage for Frisch's stunned reaction to Rasch's description of the separability of the parameters in his model.

These problems are far from solved, though the common mathematical structure of the laws of the human and natural sciences can provide a model to follow. A good place to start exploring the potential of this common model may be in an historical instance where physical measurement was difficult or problematical. (Researchers in the human sciences may be quite surprised to discover that measurement in the natural sciences, engineering, and economics is not as obvious and simple as outside consumers of the results sometime assume it to be.)

For instance, the question as to whether even physical forms of capital are sufficiently homogenous to justify estimates of aggregate value provoked, in the 1950s and 1960s, what came to be known as the debate of the two Cambridges. English and U.S. economists argued at length as to the consequences of the fact that different forms of physical capital necessarily have different human and economic values, even when their unit costs might be identical (Putnam & Goss, 2002, p. 8; Brown, 1980; Diewert, 1980; Denny, 1980). More recently, the debate has expanded to include the intangible assets of human, social, and natural capital, since the impact of these on investment returns opens up the possibility for new longer term, sustainable profits (Andriesson, 2003; Ekins, Hillman, & Hutchison, 1992; Hand & Lev, 2003; Hawken, Lovins, & Lovins, 1999). In this context, all of the disparate issues of probabilistic measurement theory and the social studies of metrological networks come to bear in economics, but with little or no awareness on the part of economists that other fields are successfully addressing structurally identical problems of quantification and mathematical inference.

No one should infer from any of this, however, that the problems of capital aggregation have been solved, whether for physical, human, social, or natural capital. Recent research raises far more questions than it answers. What sets the new questions apart from the usual ones, though, may be the directions in which they lead.

Application to Non-traditional Forms of Capital

Over the course of the last three decades, a wide range of different forms of valued constructs, domains, factors, or variables have come to be referred to as capital. And so now it is common to hear of human capital, social capital, political capital, community capital, literacy capital, natural capital, etc. It has been suggested that the usual 3-capitals model (land, labor, and manufactured capital) be expanded to a 5-capitals model (natural, human, social, financial, and manufactured) so as to both enrich the conceptualization of capital as well as to provide a more comprehensive basis for accountability (see Hawken, et al., 1999, p. 4, for a 4-capitals version that conflates the human and social). Human capital is far more diverse and valuable than the reduction to labor alone can express, for instance, just as natural capital offers a variety of essential processes and products that amount to much more than the mere value of land.

In addition, social capital has been described as perhaps being more important to the success of capitalism than any physical form of capital (Putnam, 1993, p. 183), and rightly so, since it seems likely that social capital provides the context of a nurturing environment in which any other form of scientific or political capital is brought to life (Shapin, 1994; Fukuyama, 1995). However, little attention has yet been paid to the metrical mysteries of social capital or any of the other new forms of capital that have recently emerged. Far from being esoteric academic exercises divorced from data or practical application, the purpose of focusing attention on these issues combines theory with experiment, and mathematical beauty with pragmatic utility.

Will it be possible to see all of the forms of capital through their birth in the manner of philosophy's ancient Socratic midwife, checking to see that they are fully formed and able to live independent lives? What would it mean to measure the properties of these forms of capital and bring them to life in a manner analogous to the way the geometrical surveys of property incorporated in titles and deeds bring it to life as fungible capital?

Two examples are readily available. The first is in an early gestational period of its development, and the second is at an early stage of maturation. The contrast will serve to bring out the continuum along which new forms of capital are brought to life.

Functional Independence in Mobility and Activities of Daily Living (ADL)

Four different functional assessment scales were identified as addressing mobility and ADL skills such as feeding, dressing, bathing, getting in and out of a chair, walking, stair climbing, etc. (Fisher, 1997). Each of the scales was used in one or more published studies to assess the functional independence of people receiving physical medicine and rehabilitation services in clinics or hospitals in North America. In the eleven total studies published, sample sizes varied from about 50 to over 26,000. Each data set was studied so as to test the hypothesis that the items on the scale defined an invariant (stable) profile of quantitatively additive and divisible magnitudes that would remain constant across subsamples or other samples from the same population.

No study authors concluded that their data did not comprise evidence of a single additive and divisible functional independence construct. Scale values were estimated and reported for all items in each study. A general pattern was observed in the item orders across studies. Feeding was always the easiest task (garnering ratings indicative of higher levels of functional competence), and stair climbing, the hardest (garnering lower ratings). In between, getting in and out of a chair was easier than walking, and upper extremity dressing or bathing was easier than lower extremity dressing or bathing.

The average of the 55 correlations across studies for the similarly focused items was .93; the mode (most frequent value) of the correlations was .98, where 1.00 would indicate perfect correspondence across studies. These results strongly suggest that the functional independence construct is stable across instruments and across samples, with the meaning of the thing measured rigorously independently of the scale items carrying it.

The implication is that functional independence exists as a potentially fungible form of capital. The construct convergence of the different studies employing different instruments on different samples at different times and places is a compelling example of the way in which a form of capital can function as an agent of agreement (Wise, 1995). But to bring it to life, more will need to be done. The convergent scaling results alone will not suffice to give birth to a common currency for the exchange of functional independence value. Rather, researchers will have to follow in the steps of their predecessors in other fields, and will have to forge the networks of relationships through which the values of the laboratory will be exported to the front lines of clinical practice, accountants' desks, certification agencies' evaluation records, and researchers' comparisons of experimental treatments. To see how this might be done, we turn our attention to the next example.

Reading Ability, Reading Comprehension, and Readability

The Lexile Framework for Reading (Stenner, Burdick, Sanford, et al., 2006) capitalizes directly on Rasch's (1960, p. 115) assertion that the reading ability of a child can be measured with the same kind of objectivity as her or his weight. Today the predominant metric for the measurement of literacy capital is Lexiles. That metric is built from an approach to reading measurement that matches readers to text, and that measures both reader ability and text difficulty on the same scale. Educators are thereby enabled to manage reading comprehension and to encourage reader progress by providing texts consistently targeted at the comprehension rate needed for students to enjoy, and feel successful at, reading.

Tens of thousands of books and tens of millions of newspaper and magazine articles have been calibrated—more than 450 publishers routinely estimate the reading difficulty of their titles in this metric. In addition, all major standardized reading tests and many popular instructional reading programs can report student reading scores in a metric that is comparable across states, school districts, grade levels, and specific curricula.

A common metric for the measurement of reading ability give educators the confidence to choose materials they know will improve student reading skills across the curriculum and at home. Because so many educational products now incorporate a universally uniform reading ability and text difficulty metric, teachers can connect all the different components of the curriculum in a common framework. The foundations are being laid in this process for teachers and researchers to begin thinking together on a new, collective and social level, as has been so convincingly demonstrated in the history of the natural sciences (Latour, 1987, 2005; Wise, 1995).

Conclusions

We manage what we measure, and what counts gets counted. These principles are transparently and implicitly embodied in highly effective and powerful ways in the transferable representations that make capital fungible (De Soto, 2000). Money, checks, titles, deeds, stocks, bonds, and other financial instruments provide precise measures of amounts of value, and so make that value manageable.

The intangibles movement (Andriesson, 2003; Hand & Lev, 2003) in human resource accounting has accordingly, then, rightly identified human and social capital (broadly taken to include intellectual capital as well), in particular, for better measurement, since it is a rich source of potential new gains in productivity and efficiency. Unfortunately, the resolution of the mystery of capital offered by Latour (1987, p. 223) and De Soto (2000) seems to have gone unnoticed by those who seek to better measure, and to thereby better manage, intangible, knowledge- and function-based forms of capital. It is also unfortunate, even tragic, that so few of those interested in better measurement in so many fields know to look to measurement theory as a resource for solving practical problems.

But even if more people did look to measurement theory for solutions, measurement researchers do not typically frame their questions in a way that leads directly to the creation of practical value. The currently prevailing sense of theory in measurement research is not the sense Kurt Lewin (1951, p. 169) had in mind when he said, “There is nothing so practical as a good theory.” It is worth inquiring a bit into the meaning of this expression.

Lewin implies that we could go on obtaining data-based calibrations of human, social, and natural capital measures forever and still not have a clue as to what we're really measuring. Good theory enables the practical prediction of measures. But almost all current research applications of Rasch’s models for measurement do nothing to actually test a theory of the variable in question, because almost no one actually articulates such a theory and offers it for consideration.

A rigorous and precise theory of a variable requires that we be able to predict an item's difficulty apart from data, and then conduct an experiment or series of experiments gathering and analyzing data to test specific hypotheses related to the theory. Though still at an emergent stage, increasing numbers of researchers are conducting such experiments

(De Boeck & Wilson, 2005; Dawson, 2002; Embretson, 1998; Green & Kluever, 1992; Massof, 2007; Stenner & Stone, 2003).

Thus, in most Rasch measurement applications, researchers are capitalizing on fortuitous accidents that happen to result in model fit simply as a result of the intersection of intuitive, culturally conditioned, and linguistic determinants of invariant, coherent meaning. Few are asking the crucial questions, such as

- “What is the mathematical law governing the invariance?”
- “How do you know that's the law?”
- “Can you substantiate your claim to knowledge?”
- “Can you show me multiple sets of independently gathered data producing estimates that conform with your theory?”
- “Do different instrument configurations developed from the theory produce commensurate measures?”

Any science worthy of the name has to provide answers to questions like these. For instance, the originators of electrical theory were faced with the problem of figuring out how far current could travel in wire before resistance would dissipate it to nothing. They had to figure out what voltage to start with, and at what intervals they had to boost the voltage by reconfiguring the volts/amps ratio, in order to have the power arrive at the destination with the desired voltage.

In other words, they had to figure out how much resistance would be posed by any of the various materials and insulators in use all along the entire cable length traveled by the electricity, and predict the expected voltage values given the estimate of resistance for any point along that wire. The first effort at laying a trans-Atlantic telegraph cable failed because theory was insufficient to the task of predicting and controlling the materials, distance, voltage, etc. Contrary to widespread opinion in academia, the practical exigencies of learning how to control consistently reproducible and measurable effects is the primary way in which theory has historically developed.

Science is so dependent on the existence of a prior technology capable of focusing attention and providing routinely reproducible effects expressed in a common metric that historians of science now use the term "technoscience" to distinguish the new sense of what science is and does from the old (Carroll-Burke, 2001; Latour, 1987; Ihde & Selinger, 2003; Law, 2002). The history of science repeatedly shows that the developers of strong theories are characterized by their familiarity with working technologies and by passionate beliefs in a single unifying principle (Carroll-Burke, 2001; Hessenbruch, 2000; Kuhn, 1977, pp. 90-7; Law, 2002; Hanson, 1958; Holton, 1988; Price, 1986). The second transatlantic cable effort, for instance, succeeded in large part because engineers figured out how to practically interpret the problem as one of laying resistance units (Ohms) end to end from Europe to America (Hunt, 1994, pp. 56-7).

Kelvin also pointed out that "British cable engineers had been ahead of physicists in the in the practice of accurate electrical measurement from about 1860 to the early 1870s" (Hunt, 1994, p. 48; also see Roche, 1998, p. 181). In fact, contrary with the popular perception of technology as a product of science, it often, if not usually, happens that widespread commercial applications of a new technology precede the science based on it (Hankins & Silverman, 1999; Kuhn, 1977, p. 90; Price, 1986, pp. 240, 248; Rabkin, 1992, p. 66). "The arrow of causality is largely from the technology to the science" (Price, 1986, p. 240), because instruments make measurable that which can be measured.

Or, as Hankins and Silverman (1999) put it, "Instruments have a life of their own. They do not merely follow theory; often they determine theory, because instruments determine what is possible, and what is possible determines to a large extent what can be thought" (p. 5). Scientific discoveries and theories do not lead to technological innovation. Rather, technological innovations spring up from within the framework of existing engineering problems. Thus, 'thermodynamics owes much more to the steam engine than ever the steam engine owed to thermodynamics" (Price, 1986, p. 240).

This point has been stressed by Wallace (1972, p. 239) in his classic study of the Industrial Revolution, where he points out that economic pressures drive the development of new technologies more often than new scientific discoveries calling for application. It is only when measures of routinely reproducible effects are expressed in universally uniform reference standard metrics, practitioners and researchers, producers and consumers, can think and act together in concert, vastly multiplying their cognitive efficiency and effectiveness (Akkermans, Van den Bossche, Admiraal, et al., 2007; Latour, 1995; Magnus, 2007). With shared metrics, producers can recognize and act on product quality improvement opportunities while consumers are basing product choice decisions on the same information.

The combined effect of these efficiently coordinated choices and actions facilitates what is being called the “wisdom of crowds” or “critical mass” effects (Ball, 2004; Surowiecki, 2004). Economies that lack the transferable representations and fungible common currencies facilitated by universally uniform shared metrics also lack the means for creating new efficiencies and new value (De Soto, 2000). Following upon Latour’s (1987, p. 223) original formulation of the social nature of scientific capital, we desperately need a new metrological infrastructure for human, social, and natural capital capable of coordinating and harmonizing economic decision-making by means of the common language that functions as a common currency for the exchange of value.

Unfortunately, the vast majority of current Rasch measurement practitioners miss this point. They make much ado about the epistemological and ontological qualities of their measures, but fail to follow through on those qualities to their logical consequences. In effect, by basing the vast majority of its instrument calibrations solely on empirical data and not on predictive theories, much of the Rasch world acts in a manner that seems to presume that electrical engineers gather data on every unit length of cable to see if it has the expected resistance properties.

But of course, electrical engineers don't do that. Once electrical resistance came to be properly understood, it became possible for any length of cable with the desired theoretical properties to do the job. The way Rasch measurement models are usually employed today, it would seem natural to think that electrical cable properties would need to be recalibrated for every different instance of their use.

But this need not remain the standard practice. In contrast with most human capital measurement activity, rigorously predictive theory ought to be an explicit goal, such that the theoretical calibration of any text can be estimated to within an error or two of its empirical calibration. As commercial test publishers have understood for decades, items need not be recalibrated for every new application. Some test publishers are gaining enough confidence to start trying out one-time-use disposable items in a computerized kind of integrated instruction/assessment. Though the idea of computer-generated tests is not new (Hedges & Pauw, 1971; Millman & Westman, 1989), the technologies needed for implementing the concept and for developing rigorous theoretical specifications are still emerging (Scalise, Bernbaum, Timms, et al., 2007; Burdick, et al., 2006; Stenner, et al., 2006).

To what extent will we achieve this kind of theoretical control over other test-, assessment-, and survey-based constructs?

Number is often thought to be fundamentally mathematical, but the identification of number as quintessentially mathematical does not make it the hallmark criterion of figure-meaning independence, since things counted may in fact not all be instances of the same thing or of the same amounts of the same thing. Thus, the common expression that a field of study is only as scientific as it is mathematical (Kant, 1970, p. 7; Descartes, 1961, p. 8; Michell, 1990, pp. 3-8) is often misinterpreted to mean that science is inherently quantitative (Thurstone, 1937; Heidegger, 1967; Michell, 2000), but what it really means is that science is nothing without living capital.

The philosophical significance of the resolution of the mystery of capital mirrors the value of this mathematical definition. Its practical consequences structure the utility and value of capital, in the sense that nothing is as practical as a good theory. It is of vital importance that human, social, and natural forms of capital should be brought to life with at least the same amounts of energy and efficiency as have been invested in manufactured and liquid capital, and property. We will be unable to nurture sustainable ecologies of living human, social, and natural capital to full maturity until our measures are up to the task.

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