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Measurement and the Structure of Scientific Analysis

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Abstract—Examination of the objectives of measurement reveals it to be part of a series or system of interlocking purposeful activities required to describe the world. The system is analysed as a five-level hierarchical structure which is complete in that the fifth level is reflective. This model may be useful in the social sciences where much measurement is either not believable or not socially relevant. In particular, the model emphasizes the need for adequate conceptualization, observation, assignment of quantity, and appreciation of relations in association with measurement; and restates the truism that measurement depends on the choice of a universally applicable natural unit with an appropriate relation to the phenomenon under study.

INTRODUCTION

RECENT theoretical and philosophical researches in the social sciences [4, 44] have clarified and consolidated the distinctions between the physical and social worlds which are of relevance to the practising scientist. The distinguishing mark of a social process lies in the ability of the social actor involved with or responsible for the process to give an account of his actions by indicating their purposes or meaning. Scientific analysis is itself a human and social phenomenon and therefore it might usefully be subjected to an analysis in which its purposes and those of its elements are examined.

Scientific work may be construed as a deliberate attempt to model or represent significant aspects of reality, and measurement is often seen as the crucial feature distinguishing scientific from non-scientific modelling. It is puzzling, therefore, to note that "we have as yet no theory of measurement... taken as an activity designed to accomplish an objective" [13, p. 84]. The usual definition of measurement as "the determination of the magnitude of some inherent property of a body" assumes the existence and description or representation of "bodies", "inherent properties" and "magnitudes" before measurement starts [16]. From this, it follows that measurement might be appropriately regarded as only one part of a more complex representational activity. In other words, understanding measurement requires an overall understanding of scientific representation.

The analysis of scientific representation to be presented here develops a hierarchical model outlined in a letter to *Nature* over twenty years ago [21]. In that letter, Gregory built on Sir Arthur Eddington's work in the physical sciences [17] and suggested that a more developed hierarchy of concepts was required for the human sciences. Eddington had developed an algebraic hierarchy by postulating an *entity*, which had existence, and an *observable*, which also had position, as prior to a *measurable*. Gregory depicted the hierarchy using information theory and postulated a *comparable* between an observable and a measurable. In this paper, I shall attempt to provide social meanings for these levels and consider whether the hierarchical structure of their system of representation is complete. It must be immediately emphasized that the system of representation referred to here is conceived as a whole and hence its elements (analysed levels) interact by definition and make only limited sense without each other.

MEASUREMENT, SCALING AND REPRESENTATION

Measurement is usually regarded as the basis of scientific work, whose grand purpose appears to be that of gaining control of events, both natural and social [8]. Boulding [6] considers measurement with logic as a general method of science, in contrast to special methods like the experiment. However, the *Shorter Oxford English Dictionary* provides about forty different meanings and definitions of measurement. This suggests that measuring is general or widespread in human life, irrespective of technical restrictions which scientists may wish to impose on the term.

Review of the literature reveals different types of theoretical statements about measurement. The commonest treats measurement as part of scientific method in the physical sciences (e.g. Campbell's writings [11]) and philosophers have long been concerned with the *theory of measurement* implicit in this work. There is also a mathematical field of *measurement theory* which has recently developed in psychology, particularly by Krantz, Luce, Suppes and Tversky [29]. This theory is to be distinguished from *measure theory* in mathematics which originated from Lebesgue's pre-war investigations into the nature of lines, areas and volumes [32].

Work in these different traditions is relevant to my theme, but specific elaboration of the purpose of measurement and its relation to the purposes of science and scientific analysis is scanty. Perhaps this is because the concept of measurement has tended to be used as synonymous with the concept of scaling.

Bridgman has conjectured how the conflation of measurement and scaling came to pass: "The primary purpose of a system of measurement may be taken to be precise description. In practice, one method of securing precision has proved to be so overwhelmingly superior to any other that it alone survives in serious scientific usage: this is specification by numbers. Measurement, then, in a very broad sense means description by the assigning of numbers." [7]. This view of Bridgman's seems to baulk at defining and restricting measurement simply to specification by numbers. Scaling, however, is so defined and restricted by all definitions.

The social sciences have used the term measurement in Bridgman's "very broad sense" and therefore equate measurement with scaling. A survey of the literature reveals that measurement (like scaling) is held to concern the process of, or rules for, assignation of numbers to values of a variable [20], or to objects [40] or to observations [38], or to quantities of attributes [33], or (more broadly) to a representation of the world [34]. In the psychological sciences, measurement theory appears to conflate the two conceptually distinct processes of representation of the world and the use of numbers. Stevens [39, 40] therefore refers to "measurement scales" and uses phrases like "levels of measurement" and "levels of scaling" interchangeably. Krantz *et al.* [29] define measurement as "the construction of homomorphisms (scales) from empirical relational structures that are useful" (p. 9). Although this approach takes the empirical relational system (the world) for granted, Krantz *et al.* are not unaware of this and emphasize the need for appropriate analysis prior to measurement. Such prior analysis is another way of referring to Bridgman's original sense of measurement as "precise description".

The distinction between measurement and scaling appears to be implicitly recognized by psychologists. For example, Hays [22], claims initially (p. 1, italics added) that "certain properties of things studied by the scientist are measured, *or given numerical values*"; but later (p. 7) he writes "the assignation of objects of observation to categories according to some classifying scheme and following some specified rules of procedure is measurement at its simplest and most primitive level", a definition of measurement with no reference to numbers. In this second definition, there is an awareness of the existence of two conceptually and operationally distinct activities: the activity of classification and the activity of assigning numbers to each category of the classification. The former activity, referred to as a primitive level of measurement by Hays, is concerned with increasing descriptive precision, that is to say, with representing the world; the latter activity, better called scaling, is concerned with assigning numbers to that representation.

Referring to scaling activities in the physical sciences, Bridgman [7] noted that "the discovery of (appropriate) measuring (i.e. scaling) operations...came only after hundreds of years of experience and experimenting and demanded a wide acquaintance with the factual content of our environment." Kuhn [30] makes the same point. As scientific experience of the psychosocial environment is relatively meagre, and its facts often contestable, we cannot simply assume that specification by numbers will be "overwhelmingly superior" as a mode of precise representation.

The principal aim of this paper is to examine systematically forms or levels of representation of the world. A model will be used to unify their underlying nature and their interrelation. In the analysis to follow, it will be necessary to tighten up on definitions. The term 'scaling' will be kept for numerical assignation to any representation and will be referred to only in passing. In the course of the analysis of representation a specific and recognizable definition of 'measurement' will be offered.

LEVELS OF REPRESENTATION

As suggested by Eddington and Gregory, representational activities can be ordered in a hierarchy of levels with each level requiring or implying action on the previous levels and on subsequent levels. The levels will be translated into psychologically meaningful terms, by considering the central human purpose served at each level and the interaction of these purposes. The mathematico-logical structure of activity at each level will be seen to lead to a typical and inherent form of error at that level. To maximize certainty, it will be argued that scientists need to operate explicitly at all levels.

Entity: Level I representation

An *entity* was Eddington's and Gregory's fundamental and primitive structure, characterized by the former in terms of existence/non-existence and by the latter as a binomial unit of information. This use of the term entity follows the *Oxford English Dictionary* and not colloquial usage which often uses it as a term for things. In psychological terms, an entity can be conceptualized as an 'idea', much as described by the philosopher, David Hume [24]. It has the property of existence/non-existence and its purpose is to reduce confusion.

From the undifferentiated totality of the universe as it impinges on him (Hume's 'impressions'), man makes distinctions, sees resemblances and creates concepts. This is the activity of representation at Level I. Ideas themselves cannot be directly observed or described, only postulated. Brown [10] makes a similar point when he argues that "the primary form of mathematical communication is not description but injunction" (p. 77); and from this notion he has developed a calculus based on the desire to distinguish. Distinctions seem to be located explicitly within the subject who chooses to make them, that is to say, they are 'in his mind'.

The formation of ideas is the commencement of knowledge (or error) and of language. Most words stand for concepts and, if challenged, can dissolve into disconcerting uncertainty and ambiguity. Sometimes the analysis of the meaning of words leads to a better understanding of the nature of things. This is a result of the closed public system of language being altered by new definitions emerging from the flexibility of inner private languages [12, 43].

Concepts are found by taking reality apart; they reify experience and can be manipulated as if they were objects [9]. They come to be held as a result of the socialization and educational process and underpin whole edifices of action and knowledge. Error at this level may have profound consequences, so profound that the high inherent uncertainty may be handled by taking concepts for granted, or by regarding conceptual analyses as metaphysics, or by political suppression of doubt.

When numbers are used at this level, they are simply labels or take the form of a switch (O/1). If the cipher 'O' is used, it is conventionally taken to mean 'off' or 'non-existence'.

Concept learning or creation is always dependent upon particular concrete examples and to relations with other concepts, that is to say, to different forms of representation to be described in sections to follow. This exemplifies the general rule that representation at any particular level always requires representation at other levels as a check on validity. There are, however, many concepts vested with belief despite lack of validity. Priestley, who discovered oxygen, adhered to the concept of phlogiston till his death. Entities like God may be said to be unscientific or invalid, though this does not mean they are unimportant. Given that valid concepts have been said to have the property of existence/non-existence, it would be confusing to say of an invalid concept that it does not exist. The status of invalid concepts is perhaps better described as 'imaginary'.

Before describing the next level of representation, it may be useful to explain how the levels are built up. The concept central to each level may be termed the *fundamental idea* (or concept or distinction or entity). Thus 'idea' is the fundamental idea at Level I. Subsequent levels of measurement are made up by adding, one by one, further fundamental entities. There is a conjunction of 'idea' with another entity at the second level, these two plus another at the third, still one more at the fourth, and a final addition to make five at the fifth level. The minimum number of distinctions required for any particular example of a level of representation appears to correspond to the number of that level.

Observable: Level II representation

At the second level, the existence of the primary entity is taken as given and the issue is how this existence is made manifest, or is to be established. Conjoining some primary entity (a specific idea) together with the second fundamental entity 'thingness', results in something corresponding to Gregory's *observable*. Observables which are static are usually called 'objects' and those which occur through time 'processes'. This form of representation is usually called 'making observations' or 'classifying', and its purpose is to make public what was private.

When the empirical nature of the scientific task is emphasized, facts are located at Level II [23]. A Level I entity, such as 'redness', 'intention' or 'freedom', could perhaps be termed a subjective fact. However, it becomes an objective fact and socially sharable only if it can be pointed to and recognized by another person: for example, 'a (particular) red', 'statement of intention' or 'free speech'. As these examples suggest, a minimum of two intersecting entities appears to be required for an observable. When the universality of the concept is converted into the particularity of the thing, an important qualitative change results. The observable never matches the entity exactly: it lacks purity, as it were, by its embeddedness in the world. This difference has preoccupied philosophers and remains a recurrent source of idealist criticism of empirical research.

The move from Level I to Level II measurement, when made explicitly, is usually called *operationalizing a concept*. Operationalizing a concept poses the puzzle about some particular thing as to whether it fits the operationalization. The measurer wonders "is that it?" or "do I include or exclude that?"

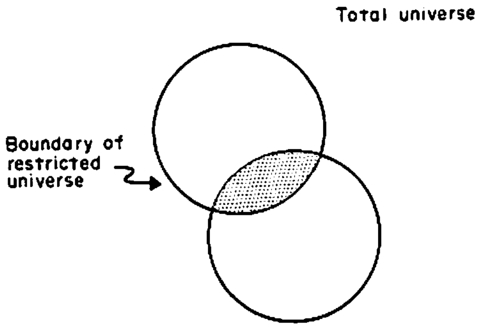

Fig. 1. Venn diagram showing entities and an observable. The shaded portion is an entity within the total universe or an observable if a restricted universe has been specified by at least two other entities.

Operationalization depends on the construction of a boundary definition which is a set of rules for classifying an object. Such a definition depends on the observer recognizing a conjunction of a number of primary entities. Because the definition delimits a region within the total universe of possibilities the degree of uncertainty is much less than in Level I measurement. Inherent error remains and is termed *misclassification.*

The relevant mathematico-logical operation is the propositional calculus and symbolic logic of George Boole [5]. The cipher "O" (or "∅") conventionally refers to the empty or null set. Numbers are used for counting observables. The groups to which these observables belong may be identified with numbers (or other symbols) either arbitrarily or following a social convention (e.g. the International Classification of Diseases). Thus nominal scaling involves representation at Levels I and II.

Comparable: Level III representation

The third fundamental entity which may be relevant when an observable can be taken for granted is the concept of 'quantity'. Once 'quantity' is conjoined with 'thingness' in relation to an 'idea' it becomes possible to make comparisons. Hence the term *comparable*, as offered by Gregory. The purpose of this form of representation is to apportion value. The word value is often synonymous with quantity or amount in mathematics and in colloquial use. For example, in economics the *value* of a good is measured by the *quantity* of other goods for which it will exchange. A comparable is formed by ordering or ranking observables and answers the question: "Which is more (less)?" or "which is better (worse)?". Three entities seems to be the minimum required to form a comparable, that is at least two observables with one entity in common plus the entity quantity, e.g. heaviness/quantity/box or obedient/quantity/child.

Although quantity is a subjective attribution the scaling categories of 'more than', 'equal or equivalent to', and 'less than' embrace an extremely restricted universe and lead to a high degree of certainty. This high degree of certainty at Level III has been taken advantage of in the development of techniques such as 'paired comparison' [42], 'successive approximation' [25], 'reference gambles' [37], and 'minimum context of difference method' [28]. These are particularly useful when the measurer (usually a subject guided by the scientist, not the scientist himself) experiences difficulty due to excessive uncertainty. Error is still inherent at this level, and takes the form of *systematic bias*, a repeated over-valuing or under-valuing.

Comparables can be ordered and numbers can be assigned which take account of this order by reflecting a monotonic transformation of the scale of rational numbers. This results in an ordinal scale. Extrapolation and insertion of new comparables within the number series is possible. The cipher 'O' is conventionally used to represent equivalence (e.g. tied ranks), equilibrium (e.g. on a weigh balance) or neutral (e.g. on bipolar scales of attitude or agreement).

Krantz *et al.* [29] suggest that analysis (i.e. conceptualizing the issue) and measurement (i.e. scaling) typically commence with an ordering operation deemed acceptable. In other words, a Level III operation (ordering, comparing, assigning quantity) may be the precursor of new ideas. According to Krantz *et al.* the scientific theorist manipulates order to yield structure and then searches for qualitative laws satisfied by the ordering and structure. Using the schema of this paper, the argument runs as follows: because order depends on difference within a distinction, the discovery of order may suggest the distinction.

Aleksandrov [1] supports this notion that comparisons generate ideas in his claim that three steps from property to concept may be seen in development from primitive culture. In the first phase a property is defined by direct comparison e.g. 'like a crow' or 'as many as on a hand' (i.e. Level III). In the second phase an adjective appears, e.g. 'a black stone', 'five fingers' (i.e. Level II). In the final phase the property is abstracted and may appear as such e.g. 'blackness', 'five' (i.e. Level I).

Activity at Level III has a concrete and specific quality in that ordering or valuing is tied to a particular situation. To continue Aleksandrov's metaphor, there may exist a land without crows and with six-fingered people but with a need to represent 'blackness' or 'five'.

Measurable: Level IV representation

The fourth level of representation deals with this problem by the addition of a fourth fundamental entity: the idea of a 'generally applicable unit'. The scientific community operationalizes this concept by deciding upon a comparable called 'the standard'. Because the choice of standard is arbitrary, lengthy complex efforts may be required to ensure social concensus. Natural rather than psychosocial phenomena are used as standards to minimize changes over time. However, difficulties remain: for example, atomic and gravitational standards for time appear to be changing relative to each other.

At this level, quantity is taken for granted and the puzzle of the human measurer is 'how much (in an absolute sense) is it?' This is the usual meaning of 'making a measurement'; and the result may be called, following Eddington, a *measurable*. The physicist's fundamental and derived measurement which refers to inherent (physical) properties conforms to this definition [11]. A similar situation holds in biology, where, for example, drug potency is measured using a standard. The standard is chosen so that differences of log tolerance between it and the drug are little affected by systematic differences between groups of animals. Such an approach meets a prime requirement of a 'generally applicable unit', namely, reproducibility to within close limits at different times and places [18].

Probability is an interesting example for our purposes. It may be defined as a subjective amount of expectation or belief a person has. This definition, dealing only with quantity and expectation, is at Level III. It may also be defined at Level IV, as a property of physical systems in which events occur in a consistent but not unique way. This latter phenomenon can be used to obtain a generally applicable quantified measure of the Level III phenomenon. The standard unit is revealed by converting the probability into odds, which have the form *x to 1*.*

The advantage of generality and abstraction at this level coincides with a loss of contact with the specifics which can be disturbing. For example, if a child is the basic unit used to measure family size, then the resultant mean size of family of 2.15 children is meaningful but intuitively bothersome. This measurable may be more or less useful than remaining with observables and tabulating frequencies of families by numbers of children.

Relatable: Level V representation

We have completed the hierarchy offered by Gregory; a hierarchy, it will be recalled, whose levels are each deeply dependent upon each other. The remaining question is whether there is a form of representation epistemologically necessary for previous levels or implied by previous levels, or intuitively required for a system to represent the world. There does indeed seem to be one further essential, and apparently final, possibility: a representation may be constructed by connection (relation, interaction) of already formed representations. The fifth fundamental concept is therefore 'relation' and so perhaps a product of the level could be labelled a *relatable*. This would be a fifth level which through its reflectiveness would complete the hierarchy.

The act of representation is usually expressed as relating (setting out a relation) or formulating (making a formulation) and its purpose is to understand how things fit together so sensible action can ensue. Without a statement of relationships, other representations such as observations or measurements are not felt to be understandable or usable. The puzzle therefore posed at this level is 'What is it about?'

A simple relatable is a rate. Thus a statement that town X had 280 road deaths, a count of an observable, is difficult to use on its own. It is necessary to know the time over which this count was made and the population of the town. The rate, e.g. 3/10,000 population/year, contains 5 entities: road deaths = observable = 2 entities, 10,000 population = 1 entity, year = 1 entity, per = 1 entity. Another common relatable, the 2 × 2 contingency table, is made up of counts of two observables and the relations between them and also consists of 5 entities. It should be noted that the relatables are the 'rate' and the 'contingency table', not the actual numbers. Numbers at Level V are ancillary, and serve lower level purposes like labelling, counting, ordering or arithmetical combination as required by the nature of the relatable. The cipher 'O', however, may also be used in a metaphorical fashion.

The formation of a relatable not only impregnates concepts, things, comparisons and measurements with meaning, but seems also to impel the measurer to action. (It will be recalled, see p. 1, that action on the world was proffered as the underlying purpose of scientific endeavour.) Finding that 80% of smokers but only 10% of non-smokers have cardiovascular disease by age 65 naturally generates the logically invalid thought 'smoking is bad for you' followed by some further thoughts like 'it ought to be banned' or 'I ought to give it up'.

Association does not imply causality, because it may be a reflection of a common factor. Since it will

* Another example of this is apparent in comparing objective and subjective properties of sound. Amplitude (intensity) and frequency are the Level IV correlates of the Level III representations, loudness and pitch. The parallelism holds only over a limited range and in a non-linear fashion; and is neither exact nor absolute. This difference when the 'same' property is represented at Level III or IV seems analogous to the change in moving from Level I to II representation mentioned earlier (p. 3). In both cases the subjective is being objectified and being altered in the process.

never be possible to be sure that common factors have been ruled out or that the most suitable relationships have been investigated or explicated, there will be inherent error at Level V. It can be described generally as 'missing the main point' or more specifically as 'forgetting to control for X' or 'omitting the relevant variable'. It results in a high degree of uncertainty. Relations, however, can be converted to conjectures and explanations can be sought. This moves the scientist out of the realm of representation *per se* into the domain of hypothesis testing.

Level V representation may use existing representations in a new way, setting out new patterns and links and creating meaning and impetus to action. Unsolved problems are often first tackled at Level V by the use of metaphor [31], that is by applying patterns from one context to a new situation. When this occurs the scientific task requires the removal of extraneous relations included within the metaphor. However, unshackling the mind from the metaphor may be difficult.

If the problem of existence may be said to characterize Level I; then the problem of essence seems to characterize Level V. The method of intuitive grasp of the essence has, since Plato and Aristotle, been the hope for ultimate infallible explanation.* It seems that knowing the world means knowing relationships—usually described as between ideas, facts, events or structures; or between context and content, or theory and data.

Without a statement of relationships, it feels as if the essence is lacking. These relationships may sometimes be stated as a 'formula', but it may be preferable to aim for a precise formulation of relationships rather than a formula. Formulae and formulations symbolize, summarize and promote further investigation of phenomena. For example, the essence of sound is the variation of air pressure with time; plotting this produces a wave whose amplitude corresponds with the human experience of loudness, and whose frequency relates to pitch. Similarly, the essence of a managerial relationship is accountability for the quality of work of a subordinate; articulating this in organizations leads to clarity as to the requisite authority for managers and the recognition of discrete levels of managerial work [25].

* Insofar as essence in the human sciences is embodied by purpose, infallibility is possible, e.g. it is the essence of a hammer to be used for driving in a nail by hitting it on the head. Infallibility is possible because essence lies in intention and is prior to the object. Measurement is a tool, not unlike a hammer, and this paper has aimed to avoid the sterile verbalism so likely when asking 'what is' questions (and so criticized by Popper) through concentrating on 'what is it for?' The discovery that measurement was part of a structure underlying scientific practices aimed at representing the world has been the consequence of pursuing this line of thought.

DISCUSSION

Idea, thingness, quantity, standard unit and relation have been proffered as the fundamental concepts which progressively concatenate to form self-contained representational systems leading at the final level to a sense of completeness in our representation of the world. The details of the model are summarized in Table 1, which lists the five levels with their suggested labels, and indicates the various mathematico-logical and practical activities which create them. To demonstrate the self-contained coherence and identity of each level, the table also lists the characteristic purposes and puzzles; the typical forms of error and sense of uncertainty; and the differing uses of numbers, the operator '=', and the cipher 'O'.

An interesting feature is the hierarchical pattern of five levels which is concordant with the general analysis of logic and human action suggested recently by Jaques *et al.* [26]. A similar general five-level hierarchical model has been offered by Beer [2, 3] to fit systems which are subjectively defined and embody human purpose. These authors have insufficiently explicated the criteria by which the hierarchy of scientific representation could be checked against their models. However, some suggestive similarities with the model of Jaques *et al.* may be noted: the pattern of uncertainty in the hierarchy; the emphasis on intuition at Level I; the flexible use of rules at Level II; the seriality at Level III; the generalization and abstraction at Level IV; the universality and completion at Level V.

Krantz *et al.* [29] briefly touch on many of the issues raised in this paper with similar conclusions. As there is little else in the scientific literature for relevant comparison, the discussion will be limited first to an example of the application of the model to a subject of my own current interest, health; then to the way the model values both objectivity and subjectivity in scientific work; and finally measurement in social science will be touched on.

An example: 'health'

The model's chief value is that it distinguishes and links together entities that are frequently confused. These are: concepts (I), things (II), attributed qualities (III), inherent properties (IV) and relations (V). When a term such as 'health' is used it is often difficult to know what the author means to refer to. Is 'health' to be taken as a concept (I) or a thing (II)? Is 'health' to be a thing in itself (II) or a property of someone/something (III/IV)? Is 'health' seen as a property inherent in a person (IV) or attributed to

Table 1. Levels of representation

Level and label	Mathematicological action and practical activity	Composition and *fundamental entity*	Purpose and puzzle
I Entity	Making a distinction, i.e. identifying or distinguishing	1 entity: *Idea*	Reduction of confusion. Does it exist?
II Observable	Making an intersection, i.e. observing or pointing to	2 entities: Idea *Thingness*	Making public what was private. Is that it?
III Comparable	Making a comparison, i.e. ordering, ranking or valuing	3 entities: Idea Thingness *Quantity*	Apportionment of value. Which is more?
IV Measurable	Making a measurement, i.e. measuring	4 entities: Idea Thingness Quantity *Standard unit*	General application and coverage. How much is it?
V Relatable	Making a relation, i.e. connecting or formulating	5 entities: Idea Thingness Quantity Standard unit *Relation*	Basis for action. How does it fit in? What is it about?

experience as a concert pianist and it depends on the universality of neuro-biological activity. Jaques [25, Ch. 6] discovered a valid measure of responsibility in work, time span of discretion. Time is central to work and a natural phenomenon.

For many non-scientific purposes, Level III representation and ordinal scaling are quite adequate for both physical and psychological phenomena, and because of their subjectivity and specificity may be preferred. Indeed the move from III to IV, from the context-bound subjective representation to the generally applicable objective measure, as in the examples quoted, tends to evoke an instinctive and not wholly irrational opposition.

CONCLUSION

Lord Kelvin said "when you can measure what you are speaking about, and express it in numbers, you know something about it, but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind... you have scarcely advanced to the stage of science" [41]. Unfortunately measurement has become a criterion of science, particularly in the human sciences, without a full awareness of the infrastructure of assumptions that sustain it. Jones [27], speaking in the spirit of the earlier quote from Bridgman, explains that Kelvin got it the wrong way round: "measurement is only sensible when you know a good deal about what you are talking about".

Measurement is one crucial hierarchical step in the representation of whatever it is you are talking about and must be seen simultaneously in the light of conceptualization, observation and assignation of quantity as well as relations to other representations. If this was a must in the physical sciences, then it is certainly so in the social sciences. Because the total system has components of a very high degree of uncertainty, apparent accuracy can be misleading, and subsequent hypothesis testing irrelevant. Much work in psychology, sociology and even economics reveals a spurious search for precise measurement which has manifestly lost contact with the reality claimed to be under study. By and large, researchers in such fields study their own disciplinary, or even sub-disciplinary, output and can therefore make little practical contribution to society.

The analysis of representation as a five-level system of hierarchical operations can be evaluated by the twin criteria of correspondence and coherence [36]. First, does it reflect and include the various scientific practices loosely labelled as measurement? Examples have been included which suggest that the theory encompasses a wide variety of such scientific practices in the physical, biological and psycho-social sciences. Second, "does it proceed from some simple, new and powerful, unifying idea about some connection or relation between hitherto unconnected things?" [36, p. 241]. The unifying idea offered him (III)? Is 'health' viewed as an idea (I) or as a relation between physical, psychological and/or social phenomena (V)? These questions gain meaning from the questioner's purpose and the context in which they are asked.

Let us consider the example of 'health' further. The conventional empirical approach is to regard 'health' as a *variable*, invisible and unmeasurable, and then to choose *indicators* which can be scaled and are believed to be strongly 'correlated' such as number of visits to the doctor, hemoglobin level, degree of disability, or even death. Links between the indicator and the variable are characteristically tenuous and "to treat them now as objective definitions of unanalysed concepts is a form of misplaced operationalism" [29, p. 32]. This approach leaves the meaning, essence and existence of health shrouded in obscurity.

The frustrating question 'What is health?' is unlikely to take us much further but the structure of representation suggests a way in. The use of the concept 'health' would be regarded as the first act of representation: it is a particular distinction at Level I which required validation in its own right. At Level II, the notion and operationalization of a healthy person or healthy act or bodily health would be invoked and investigated, based on the meaning developed at Levels I and V. At Level III, the idea of quantities or degrees of health, or better and worse health requires consideration. The determination of an appropriate fundamental unit applicable to all people at all times and in all cultures would be needed for Level IV measurement. Such a unit should be intrinsic to health (as pitch is to sound, or discretion and time to work). Finally, health would have to be seen as a relational structure at Level V. Focusing research on a particular level may depend on circumstances and the scientist involved, but all levels are of concern.

Objectivity and subjectivity

Analysis of the various levels brings a new perspective to the controversy concerning subjectivity and objectivity in scientific endeavour.

All scientific work includes, implicitly or explicitly, representation at the various levels described in this paper. The sense of subjectivity or objectivity in representing seems to correspond to the site inside or external to the person, respectively, where the experience of the activity appears to take place. Scientific work then appears to have both subjective and objective components with the levels being formed through successive moves between two states. The most recently added fundamental entity determines the sense of location of the representational act. Thus an entity (I) is an idea and private, i.e. subjective; an observable (II) is formed explicitly to locate the idea in an external object and make it public, i.e. objective; a comparable (III) is formed by the subjective sense of quantity; a measurable (IV) locates this in the external world by using an external socially sharable unit and therefore is objective; and finally, a relatable (V) moves the measurer back to the subjectivity of perceiving paterns and relations.

In scientific discussion, representations at Levels I, III and V get labelled 'subjective' and at Levels II and IV 'objective'. In line with this, probability notions are meaningful at II and IV, while plausibility applies to I, III and V. Researchers who operate mainly at objective levels, II and IV, may risk making serious I- and V-type error, i.e. making the wrong distinctions, using unsuitable categories, examining unpromising relations, or forgetting to control for or take into account crucial factors. Convincing but meaningless results may emerge. These are the mistakes that statisticians constantly warn about [15, 19]. Researchers who operate mainly at subjective levels I and V (both possible and desirable in the social sciences) run the risk of II- and IV-type error, i.e. living in a private world, losing contact with external reality, and producing findings of limited application. Plausible, satisfying and apparently meaningful fantasy may result. These are the mistakes that philosophers tend to emphasize [35, 36].

All researchers seem happy to operate at Level III. Many experiments in biology, medicine, agriculture and industry do not establish absolute values (IV) for efficacy of some treatment but are designed to determine that it is better (III) than some alternative [15].

Measurement in the social sciences

Workers in the social sciences have been preoccupied with the possibility of 'ratio scale measurement' and, because of this, have sometimes been accused of attempting to ape the physical sciences. In the model, there is no inherent difference in the principles of measurement in the social as opposed to the physical sciences. Psychological and social activities and experiences are grounded in the natural world and therefore potentially capable of generating Level IV measurables. It is only necessary to choose a suitable, universally applicable natural unit with the appropriate relation to the psychological or social phenomenon under study.

Examples have been provided by imaginative workers. A whole scientific field has emerged based on that most human of phenomena, decisions [37]. Judgement, uncertainty and value (utility) expressed at Level III can be measured using probability measures or odds at Level IV. This is based on the universality of mathematics. Clynes [14] measured emotions validly using transient finger pressure. He obtained the idea from his early

Table 1. Levels of representation

Inherent error and degree of uncertainty	Use of operator '='	Use of cipher 'O'	Use of numbers
Making the wrong distinction. High uncertainty	is confused with; is identical to. e.g. 1 = Male 2 = Female	Non-existence	Labelling
Misclassification. Some uncertainty	is an example of e.g. dog = male bitch = female	Absence; empty set	Counting
Systematic bias. Minimum uncertainty	is equivalent to e.g. 2 apples = 3 pears	Equilibrium; equivalence; neutral point	Ranking
Random error. Some uncertainty	is absolutely equal to e.g. 39.37 inches = 1 metre	Arithmetical zero	Arithmetical operations
Missing the main point. High uncertainty	is a function of e.g. $y = f(x.z)$	Metaphorical use, e.g. not relevant, not useful	(Non-numerical higher mathematics numbers, when used, derive from lower level purposes)

is simple but not new. It is human purpose in society brought into focus as we move back and forth between the reception of impressions and the effecting of actions.

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