Measurement, Knowledge and Advancement

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ABSTRACT

Many have observed that measurement, knowledge generation and advancement are companion activities. The evidence for this assertion comes from sources over the long history of mankind. Better understanding of these connections appears to be able to yield advances in knowledge generation systems. Current understanding of the meaningful nature of measurements lags way behind other aspects and is a major area needing attention by use of multiple styles of thinking found in both the hard and soft sciences. Internet messaging has opened up new horizons in collection, storage and dissemination of measurement knowledge. The state of understanding and trends of the relationships are reviewed in relation to measurement systems.

Keywords: Measurement; knowledge; advancement; human progress; information management;

1. INTRODUCTION

It is rather too obvious to state that measurement is found everywhere; it seems to be a necessary part of human living [1],[2]. It is also a fact that a lifetime of a person's work is a very valuable asset indeed. We like to think it is being applied to a worthy task that not only puts food on the table but is useful to mankind at large. Just why do we make measurements and seek to improve the way we do them? Are we doing this the most efficient way? These thoughts and questions are the subjects of this paper.

Human effort expended on measurement research, development and application is surprisingly vast and stems from earliest times of man. I once published a book on the historical development of measurement. At first it seemed to be appropriate to call it the *History of the Oldest Profession* but that had other conatations despite it being true!

Simply estimating the number of authors who attend the many conferences aligned with measurement in its many guises leads to at least 20,000 people being involved in its advancement at any time. That is a lot of resource.

Who seriously questions if we are doing it well? The conclusion I reach, when I look again over the literature and think back over many years of pondering about the issue, is disppointedly, virtually no one in its most general context!

The well-experienced measurement scientist or engineer will easily be able to point to the inefficient way in which much of measurement activity is practiced. This seems to arise because of: -

- the lack of a sufficiently encompassing scholarly sector, that
- develops its foundations on a sound scientific basis, that is then
- used for designing solutions to measurement needs.

It is to be observed that many measurement researchers conduct their critical thinking in relative isolation of the holistic world in which their contributions sit. The bulk of them work in the detailed depth regimes of their field.

On the other hand the bulk of practiioners who could make use of that knowledge do not make the best use of the knowledge available.

There is room for much improvement and that must start by considering the very foundations of measurement. We need to be clear about such questions as: -

- What is the purpose of measurement?
- How does measurement advance the state of human existence?
- What has man thought about the relationship of measurement and advancement?
- Where might it all be heading in the future?

To make sure that I am not being seen to be playing the ultimate intellectual here I wish to make it clear at the outset that I can fill in a few spaces for these questions but generally only point to the things on which we need to devote more research.

Every discipline needs its philosophical thinkers – given the size of measurement activity it is very short of metaphysical scholars. It is just not respectable to be too far removed from the pragmatics of getting a measuring system designed and into service. There is, however, a need to reflect on the higher-level, broader issues of measurement in order to see where we have come over time and how our overall activity might be improved.

This paper attempts to keep debate going by summarizing some key issues about the nature and relationship of measurement, knowledge and advancement, this being seen to be the dominant holistic field providing the roots of our profession of measurement.

This paper will first give account of the observation that numerous famous, and less famous (like myself), people have made.

We then will move to investigate how we gather knowledge and generally use it in the advancement of man.

Then the discussion moves on to deal with how man uses knowledge as a resource. That leads to the assertion that we are living in the next great epoch of the dissemination of knowledge following the widespread adoption of the printing press in the 17th century.

We are now in the Internet age! How this will change our knowledge management and our measurement practices will be some crystal ball gazing to complete the paper.

2. HISTORICAL PERSPECTIVES

Throughout the recorded history of man there has existed recognition of the connectivity between measurement and the acquisition of knowledge that, in turn, can be related to the advancement of man in general [3], [4].

Let us go right back to the Ancient Greeks and look at some of their writings.

Plato, or at least attributed to his school, once published in the Ancient Greek language that has come through translation as : -

"What measure is there of the relations of pleasure and pain other than excess and defect, which means that they become smaller, and more and fewer, and differ in degree. ………."

This goes on for a page or so on measurement as a way of supporting thinking on difficult subjects like 'love' and 'hate' [5]

Socrates published comment [6] on the lack of practical experience of the geometricians of his time and of their inability to prove things when there were ways existing to apply geometry in terms of magnitudes and spaces.

The lack of recorded material for the ancient times - only some 15% of the papyrus scrolls of the Greeks survived - does not give us total security to state the ancients rarely connect measurement with advancement as such. However, all the available evidence strongly suggests measurement was widely used only to support daily living.

For example the Pharaohs of Egypt used it for taxation assessment, the Romans knew about distance measures for marching troops and the Greeks had wine measures. Julius Caesar wished for a good clepsydra (water clock) for his invasion of the English. The Kings of ancient Cyrene in the Mediterranean were measured by weighing them against the annual crop of the local herb silphium. This set its monetary value rate and thus determined the state of the wealth of that Mediterranean island.

There is, however, at least one clear case of measurement assisting advancement of more remote issues than the measures for daily existence.

Around 250BC, Eratosthenes [7] set up a large-scale experiment to determine the diameter of the Earth, Figure 1. It made use of a long base line with a water-well at one end and a scaphe (kind of sundial) at the other. When the Sun was seen to be vertically overhead on the surface if the water in the well the angle of the scaphe's gnomon (shadow stick) was measured. Knowing the distance from the well to the scaphe he was able to use known geometry of the time to calculate the size of the Earth.
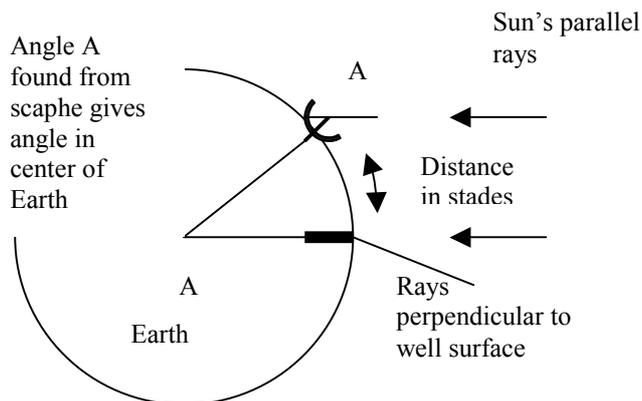
Figure 1. Eratosthene's dermination of the diameter of the Earth c250BC.

Here is clear evidence of measurement in use to advance knowledge. You may be interested to know that he actually got a credible answer but later it was shown he made two errors that cancelled each other out!

Following came the Dark Ages for which we know very little at all for some 1500 years of western history. This was 'dark' because there is little to observe. The oldest instrument in that period that I could locate information about is an illuminated manuscript from the 15th century showing a chemical balance!

The next utterance about measurement we have heard of is that of Galileo. In 1610, in Padua, he is said to have stated: -

"Count what is countable, measure what is measurable, and what is not measurable, make measurable"

Around his time the Catholic Church was the custodian of knowledge. It had its religious translating the ancient western knowledge into books, the illuminated manuscripts. They guarded the knowledge and it was heresy for a long while to further it by challenging those records.

Despite the torturing and burning of people for challenging the knowledge of the day it can be seen that measurement steadily led the way to new knowledge about many things. The 'optical glass' lens and mirror opened up exploration of large and small objects. It gave better vision to those with poor eyesight, and so on.

With investigative science opening up the revival era of acceptance and discovery we find Sir Francis Bacon in England pouring his intellectual thought into a work titled *The Advancement of Learning* [8]. There he was critical of the then current attitude to knowledge as being a god given entity. He was quite scathing of then existing philosophies. Instead, he argued a better way for enquiring about things was needed. He sought to replace the Ancient's deductive system then still in vogue, with inductive thinking.

Some assert it was Bacon who laid the foundations of the modern scientific method that we use so much today. He was not a scientist but a champion of ideas including a reorganization of science of his time in relation to public and social life. He also wrote of ideas of inventions some of which have been compared with measuring instruments existing today.

This period saw great advancement of what we now call science ('natural philosophy' then). With that came the safer ability to sail into unknown waters of the globe that had been made less risky by the development of the navigational instruments like the early wire form spheres, and astrolabes, sextants and the like.

There is considerable evidence that measurement was an important part of daily routine living and that over time it became a tool for assisting the harvesting of new knowledge for more contemplative and reflective considerations.

Moving on to more modern times we come to Prof Heike Onnes, the first person to liquefy helium gas - which he only knew he had done by shining a light across the glass tube to sense a reflective meniscus that indicated the presence of a liquid. In 1882 he had the connective words "Door meten tot weten" placed above the doorway of his laboratory. They stated "Through measurement to knowledge".

Probably the most well known statement about the relationship between measurement and knowledge is that of Lord Kelvin. In 1883, in a lecture to the Institution of Civil Engineers he stated: -

"In physical science a first essential step in the direction of learning any subject is to find principles of numerical reckoning and methods for practicably measuring some quality connected to it. I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind: it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of science, whatever the matter may be"

Kelvin was extensively published but nowhere can I find any further ideas of his on this topic. Pity!

This statement is expressing elements of the thinking paradigm known as reductionism, the main method by which we today gather knowledge in the hard sciences.

This way of thinking appears to have been first recorded a contribution of Descartes. In he stated in his 1693 *Discourse on Method* [9]: -

"…..divide each of the difficulties that I was examining into as many parts as might be possible and necessary, in order to best solve it."

He suggested that the human mind sorts out its problems and finds solutions by breaking them down into successively smaller elements until the stage is reached where they are adequately understood.

Descartes suggested four rules for "properly conducting one's reason": -Avoid precipitancy and prejudice.
- Accept only clear and distinct ideas.
- Conduct orderly progression from the simple to the complex.
- Complete analysis with nothing omitted.

In essence his method is to then solve the parts and assemble them up again, the whole problem then presumably being solved. We return to this later for the assumption about integration often does not hold.

Some argue the Kelvin approach to gathering knowledge, given above, has been over used to the extent that it, too often, can "thwart enlightened thought" [10].

A recent quotation is one by Sir Robert Walmsley upon his the launching of the UK MOD Smart Procurement process in 1999.

"We need the discipline of having to display our performance to the wider world."

Here we see the need to audit performance through well-considered measurement, declaring it in an open way because that brings about advancement.

Thus it is clear that many qualified minds have made the connection between measurement and knowledge, and knowledge and advancement.

I also made it when choosing the title for my 1979 book on the history of measurement - *Measuring Instruments: Tools of Knowledge and Control*. This distinction was made because it seems clear that measurements are made for two principal reasons: -
- As part of the application of the scientific process for obtaining yet unknown knowledge.
- As the sensing element for determining the state of a variable under control in a close-loop system. There the knowledge needed to set up the system already exists; the sensor gives the system the current state of the variable as data.

Simple inspection of where the intellectual effort of measurement is currently being deployed shows that the majority of it is devoted to the ever-deepening pragmatic issues of such technological issues as sensor design, signal processing, and instrumentation systems.

In sharp contrast by its almost total absence, is the comparatively little attention given to such issues as why we measure and how to organize it more efficiently in its various applications in generating knowledge.

It will be argued later below that this situation has come about because of the ever-diverging paradigms of scholarly research pursuit that are practiced in the two main areas of scholarship – the humanities and the physical sciences.

Some studies on the general nature of measurement are available. A few are now selected to show the range of approaches taken.

Finkelstein has covered a large range of fundamental topics over his long career. His paper of the 1999 TC-7 meeting in Japan [11] is a good summary of how far the ideas have been taken in formal mathematical terms.

The place of measurement in science is covered by Kariya's paper [12]. It gives a balanced view of the hard science involved along with the necessary early stages of idea formulation and expression of what it is about as a process of learning.

Hofmann makes the link between measurement and practical need in society [13].

Many other papers of the 1999 TC-7 meeting in Japan cover the general area of this paper. Space prevents more being mentioned here. [14].

Bartoletti et al have covered the link between instruments and intelligence [38].

Yang has approached the problem of creating a universal framework [15] from the epistemological perspective suggesting it be modeled as a knowledge oriented system – there is that connection with knowledge again. He proposes an object-oriented model [16] be used for representing measurement systems.

Many years back I also made a simplistic review of the role of measurement [3]. I felt it only touched the surface. It is clear that the problems involved are really quite formidable.

Overall there are clearly a few workers making some progress with a better and fuller understanding of the foundational issues of measurement. Sadly, the total of that work does not add up to be a dominant thrust of investigation within the wide spectrum of measurement research.

Looking back over 4 decades of involvement my view is that little has been added to the bank of knowledge on the nature of measurement and its foundations. We need to look elsewhere to see some likely reasons why.

3. KNOWLEDGE GATHERING AND ITS PLACE IN ADVANCEMENT OF MAN

It is now appropriate to review how a topic concerning the real world is investigated and how new knowledge is formed about it. Here are found some important clues as to why little progress is being made in understanding the process known as 'measurement'.

The way a person views the world is very much decided by their belief systems.

The nature of inquiry is so very different across the various disciplines [17]. Mathematicians, scientists, engineers, social science, management and so on, do not have the same belief systems and often use different ways of thinking to solve their problems.

This may come as a surprise to the hard scientist or engineer. Their thinking is so dominated by what is called the reductionist approach. Many have never realized this of themselves for they are generally satisfied with this paradigm that gives them results and one that their peers accept and reward them for using.

I recall the adverse reaction of colleagues who had come across an organizational science book on problem solving written by leading management academics [18]. They were obviously perplexed about the language and expression used in its discourses.

Some stumbling blocks for reductionists in accepting the softer sciences and humanities approaches are the: -

- Apparent lack of enough rigor of understanding and expression
- Use of unfamiliar terms and words like 'paradigm', 'metaphor', 'holistic', etc.
- Lack of ability to be precise about ideas
- Inability of humanities practitioners to be able to clearly identify the parameters and relationships of their areas of work.
- Lack of applicability of the reductionist approach that surely should be used – after all, it has and still is serving much of science and engineering very well!!

The humanities paradigm is known as the phenomenological approach. Here the observer does not metaphorically dismantle the system of interest but instead takes the viewpoint of getting inside the system of interest, injecting intervention actions to see if their current understanding is correct and is able to change the system as required. A relevant branch of this is called the Soft System Methodology (SSM) [19].

In contrast reductionism requires all of the system of interest to be dismantled and then be built up again in its new form. The sort of problem, therefore, that does not lend itself to this paradigm is one where the boundaries of influence are unclear preventing the creation of an adequately closed system model.

There is also another reason why reductionism fails in the complex systems arena. Success in understanding and problem solving is predicated by the assumption that the solutions for the sub-systems resulting from reticulation can all be integrated back into the needed whole. Slight variations in specification of those subsystems parts can have a significant impact on the performance of the whole

– to the point where the whole differs markedly from expectations.

The reductionist concept is indeed traceable to Descartes but it is not accepted all round for it does have a severe philosophical problem.

A fundamental difficulty is what philosophers call the 'Dual Body' problem. Behavior of the physical aspect of the human system is well explained by the laws and rules of physics. The mind, however, seems to behave quite differently. Its behavior defies reduction to formal description and use of the same method of scientific investigation.

The methods of inquiry, and even the scientific process of discovery, are not taught in most engineering and science courses. A result has been the widening divide between the thinking styles of the Arts/Humanities and the Sciences divide existing on the modern university campus.

A recent UNESCO meeting was held in France to discuss the problems of the world and how they might be better solved. It came to the conclusion that a 'trans-disciplinary' approach was essential. This is needed to get the many thinking styles pulling together.

The reductionist scientific process is now dissected to show where measurement is used in support of the gathering of knowledge.

In 1931 Bertrand Russell published his understanding of the basic process steps of the scientific method's.

"In arriving at a scientific law there are three stages: -

- The first consists in observing the significant facts
- The second in arriving at a hypothesis, which if it is true would account for these facts
- The third deducing from this hypothesis consequences which can be tested by observation"

The Scientific Method relies on: -

- Reducing the complexity of the variety of the real world to a manageable state.
- Performing analysis or experimentation on simple models of the world to examine a hypothesis.
- Validating a hypothesis by looking repeatedly to see if it can be disproved - the 'null-hypothesis' basis. It is actually not achieved by showing it to be always true as is commonly understood (infinite testing needed there!)
- Building knowledge, therefore, by refuting the hypotheses.

The scientific process of inquiry and its stages can be summarized as Table 1.

Areas of measurement are needed to undertake all stages of this knowledge gathering activity. Measurement is, therefore, a key part in its application. As such, poorly undertaken measurement can lead to incorrect knowledge or more usually the case, less precise knowledge possibly being mis-information or negative knowledge.

Generalized Scientific Method	Role of Measurement Theory and Practice
1. DEVELOP HYPOTHESIS	
1. Identify question/problem	1. Develop test objectives
2. Formulate hypothesis	2. Estimate performance
2. EXPERIMENT	
3. Plan the experiment	3. Develop test method
4. Conduct the experiment	4. Collect test data
5. Analyze the results	5. Calculate the measures
3. VERIFY HYPOTHESIS	
6. Check the hypothesis	6. Compare results
7. Refine the hypothesis	7. Re-run tests or extrapolate

Table 1. Stages of the measurement process and the role of measurement in its execution.

The process acquires new data from measurements made and the observer uses that data to draw conclusions about the hypothesis being developed by evaluating the data in the context of the hypothesis.

So far we have discussed the role of measurement in the scientific process. It is an easy step to see that that process is applicable to any measurement situation itself for a measurement activity is an experiment to see what you have. If the result is known, then why measure!

This is the time to review how the data flows into evaluation of the hypothesis. We need to ask a fundamental question. What is the holistic purpose of making a measurement?

In the closest inward boundary it is to satisfy the need of the person requesting the test. This is, however, a far too restricted horizon to take because that test is surely being done to integrate into a much larger problem solution.

A single measurement entity is being measured as part of a large array of measurements needed for evaluation purposes of a system of some kind. Examples might well be to assess the airworthiness of a new aircraft or to see if a medical intensive monitor unit is operating within all critical performance parameters.

The data of the test is used within a hierarchy of different kinds of measures that relate to each other. The various types of measure shown have been realized from experience and reasoned thinking that was first published for major defense projects of the USDoD. Figure 2 shows these.

To set up a system's measurement plan the Critical Issues (CI) are identified from the system requirements documentation.

Each CI is then broken down to obtain its Measures of Effectiveness (MOE). These in turn reticulate to the Measures of Performance (MOP); to the System Performance Parameters (SPP); to finally reach the Technical Performance Parameters (TPP) level.

In this way a tree of measures is generated from each CI. Of these layers only the TPP is data obtained by the hard scientific process. Once the TPP data has been obtained the values are fed upward into the tree to give the various other measures their value by direct calculation. In this way the planning gives traceability results for all measurements and only essential measurements are performed.
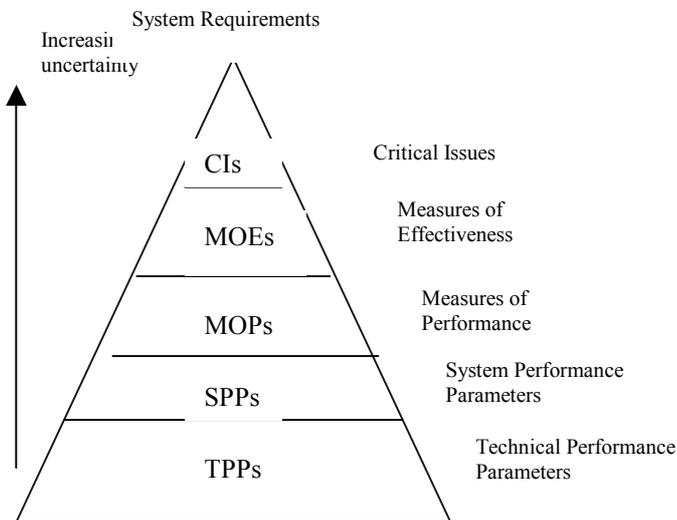
Figure 2. Different types of measures in the measures tree

As the calculation rise up the trees the knowledge becomes less accurate in its nominal value and more uncertain.

To this point I have not tried to distinguish between data, information, knowledge and wisdom. In practice they are often used in the same context yet are really quite different entities.

Rather than give here my own long maturing, but more experiential, ideas on the nature of knowledge [21],[22] I visited the library again to see what books are available on this topic.

In the Dewey system of classification the first category call class is 001.xxxx. It is devoted to 'knowledge'. The majority of the books here, however, are on computing. Few are on the nature of knowledge.

It seems to be useful to classify four levels of the cognitive entity. Using the Oxford Universal Dictionary, 1968 we get the following definitions): -

- Data
"A thing given or granted: something known or assumed as fact and made the basis of reasoning or calculation".

- Information
"The action of informing" stemming from "To put into form or shape".

- Knowledge:
"The fact of knowing a thing, state, etc." stemming from

"To recognize or identify". Also "an organized body of information".

- Wisdom:
"The quality or character of being wise" stemming from "Having or exercising sound judgment or discernment"

This gives some useful clues about their differences but we really need an explanation that is more closely related to measurement systems.

Here follows my own current definitions. My earlier attempt to define them [21] has not been improved upon by me.

Data: Raw symbols that are obtained from a measurement system and that have no assignment of meaning. They are just simply numbers, letters, ikons, cuneiform stabs in clay, etc. An example is '10' or '-'.

Information: This is data that has associated, either tagged with it or elsewhere, a small amount of cognitive material that gives it a certain meaning. Reduction of 'raw data' into 'engineering units' is an example. An example is '10m'. The assignment of a tag that has a cognitive meaning, here the distance unit 'm' for the metre, creates useful information from the number symbol.

Knowledge: This is information put into a context of a particular use. Representational information is organized into a coherent model structure. As with 'beauty', what constitutes knowledge is in the mind of the beholder and has a large degree of subjectivity.

It possesses specificity of application. For example, the raw data from a strain gauge on a wing of an aircraft for a given location and time, and with known units, constitutes a segment of knowledge.

Wisdom: This is a higher level of cognition than knowledge. It is a set of knowledge components having associations between entities. For example, the pattern of strain gauge readings across the aircraft wing may have peculiarities that suggest, to the expert mind, that it is in a an unsafe state.

These entities form the intelligence tree of Figure 3.

Knowledge is now considered to be a key competitive factor for industries and nations. With measurement being a support for the path to knowledge then surely measurement has great value in wealth creation. In Australia a political catch phrase is to become a 'Knowledge Nation' yet measurement has little place in the official research classes for support grants.

Overall what used to be called 'information' yesterday tends to often now be called 'knowledge'. The fact is that these cognitive entities have yet to be adequately defined - the debate continues.

Over time the application of knowledge has undergone three stages. Drucker [22] asserts the stages are:-

- 18th century – Knowledge applied to tools, processes and products.
- 19th century – Knowledge applied to human work.
- Now – Knowledge applied to knowledge itself.

It has become necessary to refine the classification of knowledge to meet the modern needs for using it as a commodity [23]. The simplistic classes of 'basic', or 'pure', and "applied" are no longer adequate. Blacker [24] suggests the main types of knowledge are: -

- Embrained knowledge - abstract cognitive skills
- Embodied knowledge - face to face contact
- Encultured knowledge – by achieved sharing
- Embedded knowledge – resides in systematic routines
- Encoded knowledge - held in symbols, such as in books
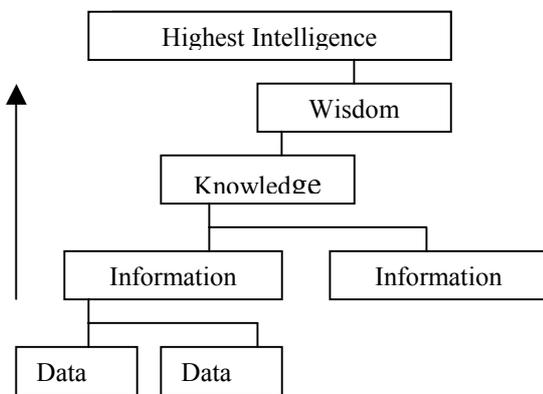
Figure 3 Intelligence tree shows relativity of the various cognitive variables.

Fleck [25] suggests another based on knowledge management needs: -

- Knowledge identification
- Knowledge acquisition
- Knowledge generation
- Knowledge validation
- Knowledge capture
- Knowledge diffusion
- Knowledge embodiment
- Knowledge realization

We can thus see that the knowledge entity that measurement assists collect is not clearly defined.

Johnson [23] asserts we are today in a global 'knowledge economy' in which 'knowledge management' and 'knowledge skills' are key factors to possess in being competitive.

However, knowledge has a range of intrinsic properties that prevent it from being traded like other commodities. These include: -

- Limited appropriability (cannot create a market once it is produced because others can access it at little cost.)

- Non-rivalry (once in use by one person others have access. There also is no need for continuing investment to maintain it.)
- Uncertainty or risk (producing new knowledge is not guaranteed from investment programs.)
- Durability (not destroyed or altered by use but increased use can add to its value.)
- Indivisibility (must be aggregated to form a coherent picture.)

The issue of just how to characterize what knowledge is seems to have been overrun by pragmatic considerations of how to use it to create wealth. Johnson also makes the observation that on the one hand knowledge is an asset to have and seek, yet to many today, gathering it can be seen as amoral or lacking in human concern.

Again we have evidence of fuzziness of our understanding of knowledge. What is clear is that today knowledge has moved from the books of the library into the corporate assets bank. It has its own industry. I will be later commenting on how this commercial interest is changing the nature of knowledge reporting and application.

As reductionists we seek a sound foundation of certainty for things we do. It is commonly thought that such security exists in hard science. The scientific process seems sound, but how good is it as a way to the 'truth'?

Despite a general feeling that there is exactness in the hard sciences there is actually no 'exact' way to assess the value of a good scientific theory. Kuhn [26] assessed the quality of a scientific theory with 5 key questions that "collectively indicate what is at stake". These are: -

- Accuracy (demonstrable performance)
- Consistency (internally and externally)
- Breadth of scope (goes far beyond local proofs)
- Develop order, in a simple way (to existing isolated laws)
- Fruitfulness (lead to new appreciations and relationships)

This suggests that measurement is also never exact. Not only is there uncertainty in the determination process itself but that the scientific principles, upon which the sensing system is based, may have flaws.

We live with this in most applications of measurement by working our systems parameters way above such thresholds. However, some practitioners cannot have that luxury. For example, in fundamental particle investigations in physics and in those safety critical systems in engineering where designs are running on the edge of knowledge certainty, these basics must be allowed for [27].

It is not too great a leap to suggest the Kuhn tests can be applied to assess the goodness of measurement systems. Take, for instance, applying them to the knowledge-based approaches used in so-called intelligent measurement.

They certainly are not accurate or consistent in their results for their outputs vary widely depending on who

selected the AI parameters. Artificial AI methods have considerable breadth of scope and are fruitful in that their architectures can be widely applied to assist other developments move forward. I am uncertain as to whether they develop order yet a good set of heuristics often can out-perform instruments using strictly hard science approaches.

That is all the space that can be devoted here to the reductionist method. We need now to draw some contrasts with the main alternative way to solve problems, exploring where measurement is used there.

The phenomenological approach of the humanities has many dimensions ranging over all manner of ways of thinking. Here we look at the so-called Soft Systems Methodology (SSM) as that seeks to understand existing techno-social systems when the reductionism problem solving approach fails - as it so often does.

The humanities' techniques tend to not be used much by engineers and hard scientists. One British engineer, Checkland, developed a systems thinking approach to life from an early age. After rising up through industry to be a leading engineer in charge of major factory operations he found that hard science was not working well enough for him.

Having had a broadened interest in problem solving he developed what has become known as soft systems thinking. The elements and structure of his approach are summed up in Figure 4.

Working around the problem-solving loop it can be seen that it emphasizes use of conceptual ideas that cannot be readily expressed in mathematical terms. It also requires the hopeful solution to be implemented into the working system. It has elements of reductionism as it has broken the system into component parts and is attempting to set up models. This supports the principle that all problem-solving starts with open thinking about concepts hoping to then progress ideas onto hard formal representation.

Checkland's work was published much as a chronology of the development of his thinking paths. It has been much tidied up and extended by Flood and Jackson [18] who laid down the main ideas along with a critical review of its pros and cons. Jackson has extended the Checkland model, Figure 4, by inclusion of how to evaluate the results of each stage of the SSM process model.

Inspection of Figure 4 shows that measurement is an essential activity in many stages of the SSM process.

Some measurement is of the hard kind - when the real system is sensed to learn of its characteristics before and after intervention. Other uses are its application to testing the behavior of the conceptual models generated.

This work has not found great following. Management finds it to hard; engineers find it too soft! It is a useful softening of the reductionist approach to make it more applicable without losing its potential formal characteristics.

So where does reductionism work and not work? There exist some simple clues.

Reductionism approach applies when:

- Only fluxes of energy or mass are involved in a network
- A sufficiently representative closed system boundary can be realized.
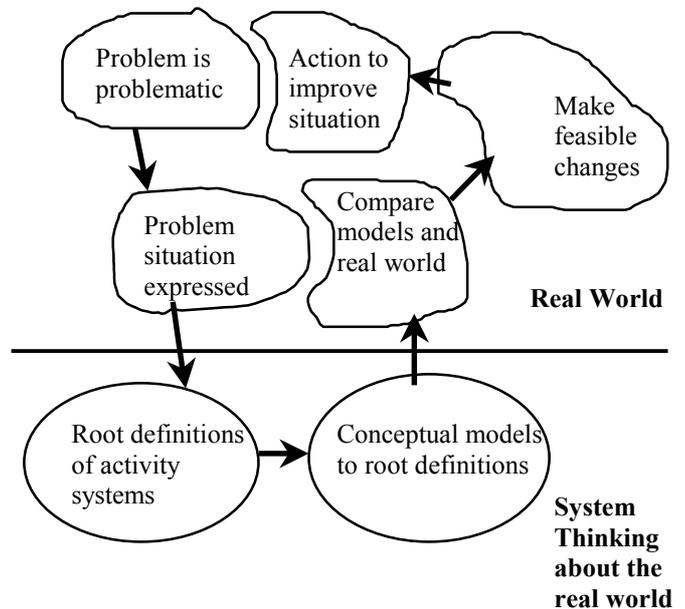

Figure 4. Checkland's Soft System approach to problem solving where reductionism does not appear to work

Soft system approach applies when: -

- The above rules do not apply
- Human cognition is part of the operation of the system, i.e. it is dominated by human behavior
- A sound set of heuristics can be realized.

It is clear that a strong connection between the gathering of knowledge and measuring systems exists and thus advancement is thus dependent upon sound measurement practices.

4. CONNECTION BETWEEN MEASUREMENT AND KNOWLEDGE

Knowledge is clearly obtained by using some kind of inquiry. Doing it certainly needs measurements to create the TPP form of measure - the data. At present human cognition is needed to interpret the data to arrive at knowledge. Could it just be feasible to go more directly from a measurement to knowledge with reduced need for human interpretation input?

Reasoning machines are getting considerable investigation. Some researchers might claim that for simple situations, we already can collect knowledge without human intervention. Artificial Neural Nets (ANNs) and Genetic Algorithms (GAs) seem to posses learning powers that are useful in creating instruments.

Several accounts describe knowledge based instrument design [28],[29],[30],[31].

Information theory does not at all cater for the characteristics of the meaning of a message. What kind of theoretical framework might assist us make a sound connection between knowledge and measuring systems?

Semiotics is the study of the characteristics of messages in general and is a well-known area in the humanities. More specifically it is the "general study of symbols, their use and relation to the objects they represent" [11].

As time passed I felt this link could be explored by coming in from the pragmatic direction. It was decided to develop a sensing system that, once instructed with rules of a situation, would relearn these for new similar situations.

An instrument was built and installed for detecting coke or stone lumps falling into large storage bins in a soda ash plant. It worked as expected [32]. However, the operator still had to make the cognitive leaps needed to generate the rule set - which he did directly by indicating zones of applicability into the frequency spectrum of sounds shown on a screen. There was no need to frame the rules as an intermediate step, as is usually needed in rule-based systems.

The difficulty of understanding how to understand the cognitive aspect remained. Eventually the opportunity came to explore this with on a more theoretical basis. [33],[34],[35] took on the task of investigating how much distortion took place to the knowledge flowing in single data logger channel. It was a challenging task that shed some light on the problem of linking data to knowledge. Cropley's work was based on semiotics applied to the generalized data channel.

Semiotics shows three principle elements are involved in message flow: -

- Semantic component: meaning of the symbols
- Syntactic component: rules for permissible combinations
- Pragmatics component: use of symbols in their systems perspective and its objectives

He was able to show that the syntactic and pragmatic components could be dealt with via reductionist means but that the semantic aspect still eluded practical measurement. As an aside, his work was not easily accepted by telecommunications research colleagues who felt that classical Shannon information theory has all the answers and that the softer work of semiotics was not appropriate for an engineering thesis.

Another contribution of relevance here is the development of the Knowledge Gathering Index (KGI) concept for a sensing system [36].

The process first identifies the various sensors associated with a given high level system performance-measuring task.

The preferences for these inputs are then ranked using the well-known Triangle of Pairs (ToP) decision support procedure.

The binary preferences are then converted into a Knowledge Gathering Profile (KGP) showing the relative importance of each sensed variable. This multi-dimensional indicator is then integrated to yield the single value number of the KGI.

This method allows competitive measurement systems to be compared and given quantitative knowledge parameters. But it also still requires the user to make cognitive choice selections.

Today it is still the case that the meaningful nature of measurement is very poorly understood.

It is not clear that this is because there has not been sufficient cross fertilization from the humanities to the sensing research area, or if cognition is a hard issue to understand in engineering terms. The large amount of work on epistemology that has yielded little understanding seems to suggest the later to be the case.

It should be remembered, however, that the humanities researchers are less likely to bring solutions to us, than we are to go find them with their assistance.

5. APPLICATION OF KNOWLEDGE

We now need to move to overview how knowledge is stored and disseminated, emphasis being on its usefulness to measurement systems. A short chronology shows the developments of knowledge storage and dissemination over time.

Ancient times (BC – 500 AD)
- Cuneiform on clay slabs (2500 yrs of astronomical records!)
- Papyrus of Egyptians, Greeks and Romans (only 15% passed down)
- Extent of Ancient knowledge – see Loebe Classics translations
- Deductive reasoning only

Dark Ages (550 AD – 1400 AD)
- 'Dark' – because little knowledge can be found
- Ancient scroll knowledge passed to Arabs
- Christian Church custodian and authors of books chained for safe keeping

Mediaeval Renaissance (1400 –1600)
- General release of content of book knowledge
- Printing press, moveable type, Gutenberg 1440s
- Classical inductive science foundations begin
- Bacon 1605 'Advancement of Learning'
- Bacon 1620 'Instauratio Magna' laid down foundations for the 'Knowledge Society"
- Royal Society 1662 was first to publish Proceedings

Current era
- Electronic storage takes over
- Massive cheap storage in millions of computers

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- Major Reference Work books less wanted by libraries and users

Arrival of the e-publication
- CDs of encyclopedias
- Server filled images, text and sound
- e-text book services in e-libraries
- Web site knowledge all over the world

The current forms of hard copy knowledge depositories are the primary sources (journals reporting original work), secondary sources (verified books and similar items) and other less easily accessed materials such as in-house journals, magazines, papers, etc.

Of these the secondary Major Reference Work (MRW) has been the dominant source covering overviews of knowledge of disciplines. It, however, now exhibits serious shortcomings in the printed form.

They are tedious and unrewarding to search, hard to copy and paste from to create 'new'; take too much shelf space with resultant overhead cost.

The MRW also, by the permanency of the medium and time to commission and print, places a time stamp on the knowledge for a 3-8 yr period; it cannot be satisfactorily updated in small increments.

Access is also limited to few of the world's people due to cost and the need to go to the place of storage. It also cannot meet the modern requirement of being able to be knowledge-managed on demand.

The application of IT to this area has been rapid. The related technology epochs in knowledge management have been: -

Clay tablets (lasted for 2500 yrs)
- Papyrus scrolls in libraries (1000 yrs)
- Manuscripts of the Church (200 yrs)
- Printing Press (600 yrs)
- Internet storage (20 and onward yrs)
- On-line e-form of Major Reference (2 yrs and onward)
- On-line Gateway MRWs with knowledge management services (wait 2 yrs) - see below.

The relationship of knowledge and advancement has several issues of importance

Knowledge is advanced when the current stock has more added and also is reinterpreted: -

- Knowledge is applied when one finds, from the vastness of supply, the portion relevant to a problem
- Ready and rapid access is required to the virtually infiniteness of the available stock of knowledge

- Knowledge stock needs more advanced tools for managing it on behalf of the knowledge customer
- Hard copy stored knowledge is just not good enough anymore – when other alternatives exist.

6. THE INTERNET PUBLISHING EPOCH

We are currently in an epoch potentially more significant than the invention of multiple copy printing press.

The use of paper as the dominant medium for storage and dissemination remains. It is, however, being seriously challenged by the electronic digital medium – the e-publishing revolution.

Here is my definition of e-publishing: -

"In the limit, all activities of the publishing, sales, updating and use of a body of knowledge are performed by use of electronic support tools and services that facilitate ease of use with high certainty of completeness and veracity, without significant delay in operation"

Take a look at the key events that have emerged in e-knowledge handling: -

- Electronic storage and on-line access provides availability of knowledge to almost everyone in Earth
- Most usability limitations of hard copy knowledge storage products are eliminated
- There are no significant storage penalties; computer technology easily caters for the demands
- Updating can be rapidly achieved
- Knowledge management and manipulation tools can be used to good effect
- Once formed it can be reused with ease.

The arrival of e-publishing will, it seems safe to assert, not only be give more convenience but it may also change the way in which we procure and apply knowledge. Already it is possible to log-on to the net with an RF instrument and request it to be; and car engine diagnostics can be done by on line as well.

It is not hard to envision the next publishing step, provision of the 'knowledge gateway' or 'knowledge portal'.

The concept of a 'gateway' is not new and it is a commonly used metaphor in computer science. Indeed MicroSoft ™ use a cartoon-like picture of a robust green door as the 'way into' their family web site pages product.

The portal is not a new conceptual idea associated with knowledge but it has taken a while to arrive as a publishing product capability.

Sir Francis Bacon's 1620 work *Instauratio Magna* used an illustration of the 'Pillars of Hercules' as its cover picture. His idea was that one sailed through the portals to access the knowledge of the world.

So what is likely to be the next form of knowledge publishing product for measurement knowledge? The answer is the gateway reference source. It needs to contain its own reasonably large body of knowledge

specifically targeting a discipline to which are added tools for managing it. It needs to make use of the features now offered by the e-file applications.

'Internally stored' features possible with e-publishing are: -

- Usually provided on-screen text with hyper linked 'pull-ups' to facilitate linking internally and externally
- Images (including color) that can be pulled up and zoomed to suit
- Audio clips
- Slides and slide shows, manual and with automatic animations
- Video clips with audio
- Multiple screens
- Interactivity with the screen

This all sums up as being whatever you can do with an 'Office' ™ tool or CD, but subject to speed restrictions of on-line services.

Knowledge location and manipulation is also possible with e-publishing: -

- Simple search – word, stem, string
- Complex search – Boolean and Expert System search
- Ontological searching – images found without word tags
- Form browser lists – terms, etc.
- Operate specialized 'doing task' tools with pulled-up tutorial assistance from the knowledge base
- 'Cut and paste' to form new combinations - such as a lecture presentation or a specification
- Operation of links to other sites
- Use its knowledge base to refine knowledge needed that then directs the user to appropriate websites for greater depth.

Externally a gateway product will link out to e-journals, e-books, e-libraries, e- business sites, e- product services, email, e-calibration facilities, product information, set up tests, run tests, take records of tests, analyse and report tests. The list is large.

It seems the only limitation that is currently obvious is the slow connection transmission speed. That should be overcome with the wideband web links now starting to installed today.

These new products will be on-line publications that contain basic verified and organized knowledge and that give access to just that set of knowledge the user requires thus avoiding the need to search the current totality of all on-line materials. An example supporting measurement systems under development today is MeasureMentor ™ [37].

7. SUMMARY AND EXPECTATIONS

The connections between measurement, knowledge and advancement have been explored in a holistic way.

It is easy to demonstrate that advancement is dependent on knowledge being available and applied. It is easy to connect measurement as a key process in gathering new knowledge.

What seems to evade us is the direct connection between the meaningful aspects of data obtained from measuring systems.

Each of these issues is important for researchers and users of knowledge to appreciate the state of knowledge of these high level aspects. It is there that major advances in technique appear to be waiting to be found.

The Internet epoch for publishing knowledge, to potentially all on the Earth, also brings new opportunities to measurement work. Use of this media has only scratched the surface of its potential to date.

It has been shown that to realize this potential there is need for much more collaboration between the hard sciences and the soft sciences.

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BIOGRAPHY

Prof. Peter H Sydenham, BE (Hons), ME, PhD, DSc, has been an active member of the University of South Australia since 1979 when he became the Inaugural Professor and Head of the School of Electronic Engineering.

In 1992 he became a co-founder of the Australian Centre for Test and Evaluation (ACTE). There he held the Chair of Systems Test and Evaluation within the Faculty of Information Technology. Peter is currently an Adjunct Professor with the Systems Engineering and Evaluation Centre (SEEC) - that expanded out of ACTE.

In 1993 Professor Sydenham was presented with the Richard G Cross medal award by the International Test and Evaluation Association ITEA, USA, in recognition of his achievements in T&E.

He has published many books, primary papers, consulting reports and technical articles on measurement, history of technology, instrument design, systems Test & Evaluation and general science.

He shares his time commuting between Australia and the UK. He is a Visiting Senior Research Fellow at the University College London where he assists Test & Evaluation teaching and thesis supervision. His major occupation is now as a Co-Editor-in-Chief of MeasureMentor, an innovative on-line knowledge service on measurement systems currently under development by John Wiley & Sons (Europe).