Measuring, Formalising and Modelling Tacit Knowledge

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Abstract

This paper provides a methodology aimed at better measuring tacit knowledge in an organisational context. Although codified knowledge and its capture is commonplace, tacit knowledge has up until recent years proved elusive in its inclusion within the organisation's knowledge base. It is hoped that by means of a triangulated methodology utilising psychological, sociological and computational methods a more effective means of capturing this knowledge may be enabled.

Introduction

All of us are familiar with codified knowledge, however few of us are comfortable with the concept of tacit knowledge for: "it is generally accepted that tacit knowledge (as distinct from intangible investment more generally) is non-codified, disembodied know how that is acquired in the informal take – up of learned behaviour and procedures" (Howells 1995 :2). What would be desirable however in the Knowledge Acquisition (KA) domain is for

> the ….. researcher to explicate the tacit knowledge …if it exists, [and] to develop new knowledge if it does not, and thereby to make the information generation – information dissipation – organisation cycle more effective and efficient (Ramaprasad *et.al.* 1996 :192)

Indeed, it is Tacit Knowledge (*TK)* or what should more properly be labelled *articulable Tacit Knowledge* (*aTK*) that provides the competitive edge to many an organisation (Zucker *et.al*. 1998; Johannessen *et.al*. 1997; Lei 1997; Howells 1995; Senker 1995; Sternberg *et.al*. 1995). We say *articulable*, because we do not believe that *all* Tacit Knowledge is able to be articulated for practical and also competitive reasons (Busch *et.al.* 2000). The acquisition of knowledge is considered to be the bottleneck in the development of Knowledge Based Systems. To address this bottleneck, current KA research efforts focus on reuse and sharing techniques such the reuse of problem solving methods (Chandrasekaran and Johnson 1993; Fensel *et.al.* 1999; McDermott 1988; Puerta *et al.* 1992; Schreiber, Weilinga and Breuker 1993; Steels 1993), the reuse of ontologies for structuring knowledge (Gruber 1993, Guarino and Giaretta 1995 and Motta *et.al.* 1999) or the development and sharing of commonsense knowledge (Guha and Lenat 1990, Patil *et.al.* 1992 and Pirlein and Studer 1994). However, the type of knowledge being reused in such approaches is typically explicit knowledge which can be viewed as book-knowledge even though the knowledge may represent what an individual has acquired through a number of sources over a long period of time. The type of knowledge we are seeking to capture is not so readily identified.

Nonaka *et.al.* (1996) have explored the relationship between *TK* and articulate knowledge (*AK),* which they refer to as explicit knowledge. In essence 4 stages have been identified:

1. from tacit knowledge to tacit knowledge,
   Socialisation
2. from tacit knowledge to explicit knowledge,
   Externalisation;
3. from explicit knowledge to explicit knowledge,
   Combination
4. from explicit knowledge to tacit knowledge,
   Internalisation (:835)

We want to break into this cycle by first identifying and measuring the existence of *aTK* and then formalising and modelling this knowledge to allow it to be taken up by others. To identify and measure *aTK* we follow the lead of many other researchers (Horvath *et.al*. 1999; Torff *et.al*. 1998; Wagner *et.a*l. 1999; Wagner *et.al*. 1987) who have employed the approach developed by Sternberg (1995; 1998a; 1998b; 1999). Once measured, we formalise and model the *aTK* using a mathematically based approach known as Formal Concept Analysis (FCA) (Wille 1982; 1997). We have developed a triangulated methodology which we are testing in the Information Systems domain specifically looking at the role of *aTK* within the computing profession. We describe our methodology in the following section and conclude in section 3 with some discussion of our approach.

2. The Triangulated Methodology

Although a great deal of literature commencing with works by Polanyi (1958), has established the notion of *Tacit Knowledge*, the actual ability to extract this phenomenon is understandably limited. Solely positivistic approaches are not considered ideal in themselves and require balancing with interprevistic methods. As a means of attempting to integrate positivistic and interprevistic approaches (Jick 1983 in Scott 1990), effective use may be made of triangulation (Scott 1990). As depicted in Figure 1, triangulation in our research has evolved to denote:

1. *aTK* testing of a psychological nature using Sternberg's measurement instruments,
2. Direct participant observation with a sociological character to validate our measurements and,
3. Knowledge modelling to add rigour to our analysis and to aid comprehension and eventual *internalisation* of the *aTK* identified. In this paper we use Formal Concept Analysis for knowledge modelling.

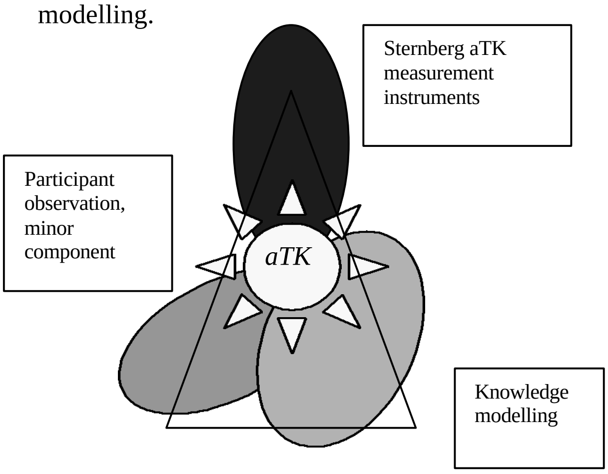

Figure 1: Macromethodology utilising triangulation to test for aTK at the individual level

2.1 Step 0: Interviews

A significant proportion of the research effort must be expended on perfecting the questionnaire, a process which usually begins with interviewing (ordinarily peer nominated) 'experts' in subject domains and asking them characteristic work scenarios and how they would have dealt with certain situations. Ethics committees permitting, it may also be advisable to interview identifiably less successful personal so that one is able to make a comparison of the differences in tacit knowledge between successful and less successful personnel (Williams and Sternberg (in press) in Torff and Sternberg 1998). From such interviews one is then in a position to establish questionnaires with appropriate answer options. As our Ethics Committee did not approve of lesser successful personnel being identified as part of our expert elicitation process (considering this to be 'covert research'), we were forced to interview all manner of junior and senior IS personnel, with a total of 12 interviews having been conducted to extract job related knowledge. Half of our interviewees were chosen through an IS managers forum which meets monthly in Sydney, the other half were junior level staff who were simply selected on a random basis. Identities of the individuals were kept confidential. This job related knowledge was then incorporated into a first draft of a questionnaire. In this paper only a minor slice of the completed questionnaire (Figs 2 & 3) is shown.

2.2 Step 1: Psychological based testing

Although to date a great deal of literature exists on the phenomenon of *aTK* in the workplace (Johannessen, *et.al.* 1997; Lei 1997; Nonaka *et.al.* 1996; Raghuram 1996; Nonaka 1991), little in the way of methodology is available for the measurement of *aTK* other than that proposed by Sternberg and his Yale University research group. The Yale approach typically makes use of a Likert scale (Figure 2), for a sequence of scenarios for which respondents are asked to pick a rank and potentially also to write 'plans of action' for how they would handle each of the allocated answers below the scale (See Scenario 1 in Figure 3). For a typical Tacit Knowledge test there would be in the order of 12 scenarios each having between 5 – 20 response items per scenario, for which a score on the Likert scale must be chosen. If one then considers that there would be an additional bibliographical component in the same questionnaire, it would not be unusual to thus have a respondent answer in the order of 130 questions. We had at first considered placing some 24 scenarios with between 5 – 6 answer items per scenario in our questionnaire, but felt that the Sternberg approach made more sense, as fewer scenarios (i.e. 12) would require respondents to shift their frame of mind to a new scenario less often, whilst being able to respond to the intricacies of a scenario in greater detail (i.e. 5 – 20 response items instead of 5 – 6). For the pilot study, the results of which make up this paper, we have used only one scenario with 5 answer items.

There are however a variety of approaches that may be adopted in scoring tacit knowledge tests according to Sternberg's team. The initial approach had been to provide a correlated score between group membership whereby a group considered to be more experienced (usually meaning senior) would be given a variable of 1, a less experienced group a variable of 2, and the least (expected) experienced group a variable of 3. A strong positive correlation between the results and the variable would thus indicate experience (greater usage of tacit knowledge) was where it was expected to be, and vice versa for a strong negative correlation (Wagner and Sternberg 1985). A second scoring approach involved the nominations (by peers) of experts, obtaining the central tendancies of their responses after they had completed the questionnaires and comparing the expert's results with all others who complete the questionnaires (in other words obtaining expert – novice differences) (Wagner 1987 in Sternberg *et.al.* 1995). The third scoring approach involved obtaining correct 'rules of thumb' from experts, placing these rules of thumb both correctly and incorrectly in scenarios and then testing who was likely to select the 'correct' rules of thumb for particular scenarios and likewise who chose incorrect rules of thumb for particular situations (Wagner, Rashotte, and Sternberg 1992 in Torff and Sternberg 1998). In this instance we piloted our study on an at hand sample, namely a group of academic and technical staff within our Department. Naturally the major study will utilise staff in major external IT based organisations. Furthermore we fully intend using the second Sternberg approach to tacit knowledge scoring whereby 'experts' are identified by peers. As the identification of experts is seen as a positive exercise (whereas identification of non-experts, or less successful personnel would be seen as a negative exercise), this is not likely to lead to conflict with our Ethics Committee, and nevertheless enables us to 'capture' IS related workplace knowledge.

Descriptive statistics along academic psychology lines then permit generalisations to be made as to the *aTK* inherent in individuals. One could say this is methodologically individualistic in its approach, insofar as testing is performed at the individual level with a view to generalising upwards and outwards. It is anticipated that the current research being undertaken by the authors may offer some insights into the testing of *aTK* at a holistic organisational level which is largely still an open question (Leonard and Sensiper 1998).

2.3 Step 2: Participant observation

Participant observation has been used by Scott (1990; 1992) to provide balance to the methodology proposed by Sternberg (*et.al*.). Scott (1990) found that "the questionnaire [Sternberg's approach] identified liberal attitudinal norms…. In contrast, the observational methods identified behavioural norms that were conservative. … The qualitative methods thus acted as a check on the quantitative method and provided valuable data on proposed role modification …" (:567). We fully intend to make use of participant observation with more of a leaning toward direct observation (Leedy 1997) in our studies of the functionality of *aTK*. Nevertheless, it should be stressed however that such observation will only comprise a minor component of the methodology given the overwhelming tendency of Information Systems work to be undertaken at a monitor where body language and otherwise obvious workplace activities are minimised.

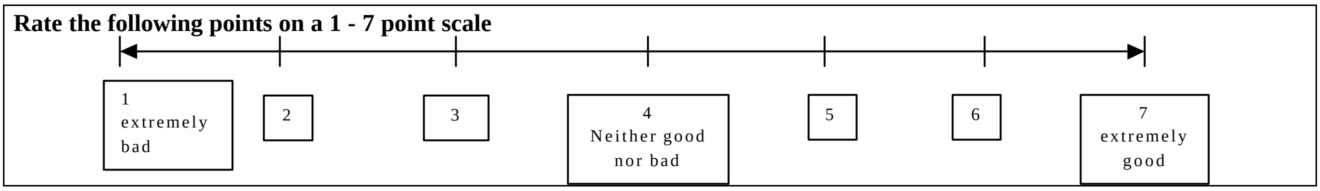

Figure 2: A sample of a Likert scale which is used to answer options

Scenario 1

You have been assigned to a team of 6 people to work on a new database system for NSW Health. This system is somewhat contentious as it will involve accessing private information on clients, nevertheless you feel that the system will favourably capture 'management reporting' information, even if privacy may be impinged upon. Nevertheless the security policies and safeguards within the organisation are felt by you to be secure enough. Although you are new to the organisation, your previous work experience is respected and you realise that there are other jobs 'out there' should you decide to 'create waves'. Within this team you are second in charge. How do you handle this situation? Do you:

1. Assign someone else to the team in your place and hope that the problem will eventually go away
2. Fully agree to the implementation of the system in the hope that the boss will notice your enthusiasm, thereby hopefully gaining you a promotion in years to come
3. Sabotage the implementation of the system, not necessarily physically but by allowing certain documentation to accidentally get 'mislaid'
4. Find that all of a sudden your diary is very full and you are unable to participate in the project because of this upcoming paper you had suddenly thought of, that you need to be giving at a conference in Singapore next month
5. Threaten to 'blow the whistle' on the project because you are concerned about ethical considerations

Figure 3: The sample scenario used in *aTK* Pilot Test in Step 1

2.4 Step 3: Knowledge modelling using Formal Concept Analysis

A further means of providing balance in relation to tacit knowledge testing is that of modelling and comparing the results of Sternberg (*et.al.*) using a set-theoretic approach known as Formal Concept Analysis (FCA) (Wille 1982; 1997). FCA views a concept formally as being comprised of a set of objects, (G)egenstande; and a set of attributes, (M)erkmale; and the relationship between them (I). Knowledge is seen as applying within a context which can be represented as a crosstable such as the subsection shown in Figure 4. This crosstable is known as a Formal (K)ontext which may be formally expressed thus:

$$K := (G, M, I)$$

A multivalued context may be expressed as a quadtuple:

$$K := (G, M, W, I) \text{ and } I \subseteq G \times M \times W$$

where the relationship I is a subset of the combined components of Objects (G), Attributes (M) and Attribute-values (Merksmale(W)erte).

We may interpret the responses to the Sternberg-style scenario as a formal context, a cross table such as the example given in Figure 4, which can be constructed thus:

K = Formal table with its corresponding data

G = The participant

M = The seven Likert scale answer options

W = The chosen answer

I = Relationship between the answer options, the choices and the participants

Kollewe (1989) has also used survey data to construct a formal context but he treats the "data of the table … as a Formal Context; the units of questioning [as] the objects, and the answers… [as] the attributes (:125). We chose to represent the data differently as it seemed more intuitive to regard the participant as the object that has a number of features such as age and position in addition to a set of responses and their values. Our approach also made data entry and validation easier as there was a one-to-one correspondence between the survey returned and the participant object.

The data captured for modelling will be based on the Sternberg scenarios and Likert scales, like those given in Figures 2 and 3. Some scenarios will also be presented in crosstable format, like the subsection shown in Figure 4. Our motivation is twofold. Firstly, we are interested to see whether the answers given by respondents to a scenario differ when the same participant is asked to provide answers in alternative formats. If answers are consistent this will add rigour to our results. Secondly, we want to avoid biasing the data we use for modelling which could occur if we needed to apply our own interpretation of the data from Step 2. Once we have the data in a crosstable we are able to automatically generate Formal Concepts by finding intersections of attributes and objects that share them, and display them as a complete lattice as shown in Figure 5.

We have conducted a small pilot with 14 participants using the scenario given in this paper. The Formal Context shown in Figure 4 only includes the data to the fifth answer option. This is a small subsection of the data we gathered for the pilot study. In the complete study there will be 700 primitive concepts (20 scenarios, each with 5 answer options using a 7-point Likert scale) plus approximately 40 IT jobs and 12 biographical factors. Handling such a large number of concepts, from which we will generate many high level concepts, is computationally expensive and impractical to display. We use a tool and technique we have developed, known as MCRDR/FCA (Richards *et.al.* 1997), to restrict the context so that the number of concepts may comprehensibly be displayed on a typical computer screen. The Concept Lattice in Figure 5 has been generated by selecting participants who in this instance saw answer option 5 as a good or better alternative. Note that good subsumes very good and extremely good. Looking at the Formal Context in Figure 4 we can see that this will include participants P1, P4, P11, P12, P13 and P14.

Scenario subject	**No.**	**Response**	**Choice**	**Participants**													
				P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**	**P11**	**P12**	**P13**	**P14**
Privacy and management reporting	5	Blow whistle	Extremely good											X			
			Very good													X	
			Good	X			X								X		X
			Neither					X				X					
			Bad			X				X							
			Very Bad		X						X		X				
			Extremely bad						X								

Figure 4: Subsection of Formal Context for answer option 5 and corresponding participant choices

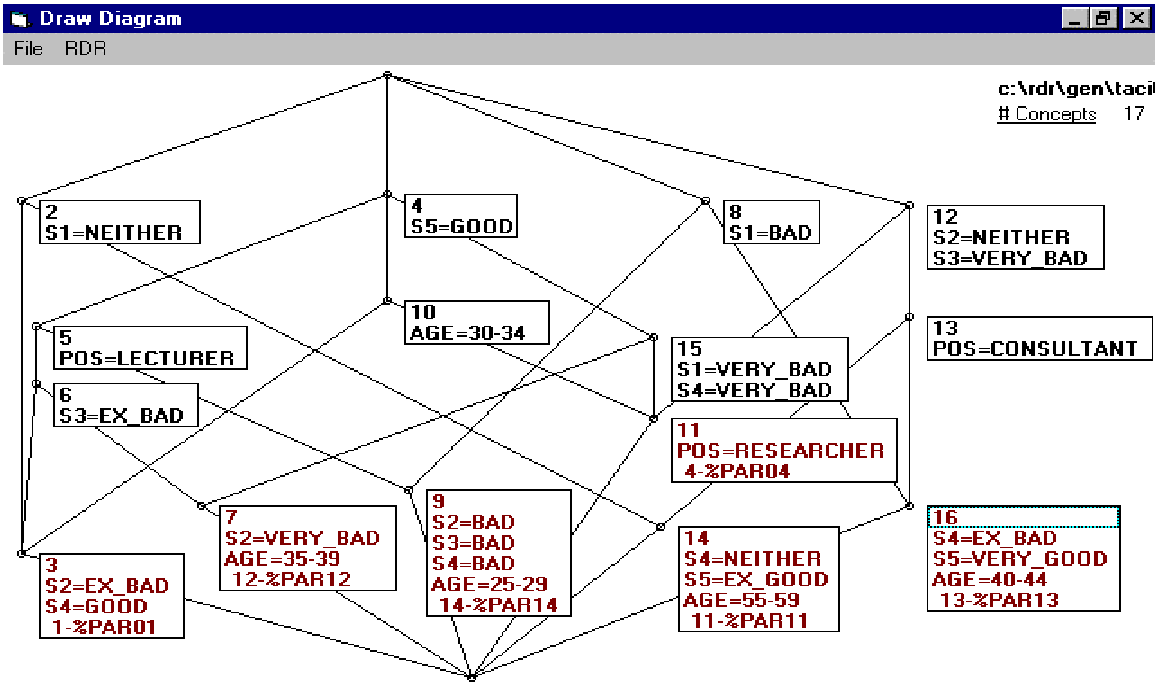

Figure 5: Concept lattice showing the features and responses of participants who found response 5 to be a good, very good or extremely good option to scenario 1

An examination of Figure 5 reveals a great deal of information. The data has been encoded to allow it to be used in our tool and requires some explanation. The 5 answer options have been identified as S1, S2, S3, S4 and S5. Participants have been identified according to the sequential number assigned to each primitive concept in the Formal Context, the % symbol and the coding PARNN where NN is the participant number (this akward labelling is based on our original use of the MCRDR/FCA tool to model rules from a particular type of KBS). Each concept in the lattice is shown as a small circle. The label describing the concept is attached to the right of the circle. Labelling has been reduced for clarity. Remember in FCA that a concept is a set of attributes and the set of objects that share them. The set of attributes that belong to a concept are reached by ascending paths and the objects that belong to a concept are reached by descending paths. Thus, we can see in Figure 5 that concept number 10 includes the attributes (or in our usage the participant's choices and features) {S5=Good, Age=30-34} and the objects {Participant 1, Participant 4}. While these two participants made the same choice for answer option 5, they differ in the positions they hold and their choices to the other answer options. We can also see that participant 1 shares certain attributes with each of the other participants except for participant 13. Participant 1 and 12 share their positions and choices to answer options 3 and 5. Participant 1 and 14 share their positions and choice to answer option 5. Participant 1 and 11 share their choice to answer option 1. It is interesting that participants 11 and 13 are both consultants who made the same choice to answer options 2 and 3 and their choices to answer options 1 and 5 are only a distance of 1 apart on the Likert scale. Their ages and choice to answer option 4 are a distance of 3 and 2 apart, respectively, on the Likert scale. The difference in ages may not be significant since both would be considered mature age and it does not indicate the number of years they have been in the consulting position. There are many further comparisons that can be made and we invite the reader to look further at some of the relationships revealed in the concept lattice in Figure 5.

3. Discussion and Conclusion

We anticipate that the structure and patterns that appear in the concept lattice, together with the results using Sternberg's measurements, will enable us to determine

1. To what extent *aTK* exists in the organisation
2. How closely *aTK* measured by way of the Sternberg approach matches with that of formal concept analysis and the various strengths of both approaches
3. What features differentiate individuals who have accumulated more *aTK* from those with significantly less *aTK*
4. Some insights into how *aTK* may be made explicit and passed on to those with less *aTK*.

The aim of this paper has thus been to present a research approach into the externalisation of *aTK*, focused particularly within the Information Systems domain. Once externalised our ultimate goal is the internalisation of that knowledge by more individuals, which should offer a number of advantages to an organization. At this point in time we have developed the triangulated macromethodology of our approach, as presented in this paper. In summary, the primary tool will be to use a Sternberg approach to *aTK* measurement, however, we seek to balance these findings with those of another quantitative technique, namely Formal Concept Analysis, whilst also making use of a qualitative participant observational approach. We have presented some of our micromethodology and given an example of a Sternberg-style scenario and some data captured in a small pilot study, which we have formalised and modelled using FCA. We are currently analysing the interviews (from Step 0) to develop scenarios and corresponding crosstables for our complete study, which will be conducted in the near future.

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