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A Framework for Knowledge Acquisition from More Than One Expert

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ABSTRACT

The knowledge required to set up an expert system is difficult to acquire from one expert, and even more difficult to acquire from more than one expert. Experts may share only parts of their terminologies and conceptual systems or may use the same term for different concepts, different terms for the same concept, the same term for the same concept, or use different terms and have different concepts. This paper provides a framework for eliciting and recognizing such individual differences. Knowledge Support System Zero (KSS0) is a knowledge support system providing an integrated set of tools for knowledge acquisition for expert systems. **Elicit** provides facilities for eliciting the important dimensions of an expert's thinking on a topic and **Socio** processes results from several experts to reveal the similarities and differences in the concept systems of different experts construing a domain defined through common attributes. It can be used to focus discussion between experts on those differences between them which require resolution, enabling them to classify the differences in terms of differing terminologies, levels of abstraction, disagreements, and so on. It allows the knowledge engineer to identify **consensus, correspondence, conflict** and **contrast** in a knowledge acquisition system with more than one experts.

INTRODUCTION

The problem of knowledge elicitation from a skilled person is well-known in the literature of psychology (Nisbett & Wilson 1977). Bainbridge (1986) has reviewed the difficulties of verbal debriefing and notes that there is no necessary correlation between verbal reports and mental behavior, and that many psychologists feel strongly that verbal data are useless. However, this remark must be taken in the context of experimental psychologists working within a positivist, behavioral paradigm. Other schools of psychology see the problem not as methodological but as psychological and resulting from cognitive defences that impede internal communication for a variety of reasons (Freud 1914, Rogers 1967). Clinical psychologists in particular have developed techniques for making use of verbal interaction to identify underlying cognitive processes, for example through structured interviewing techniques. These can be used to by-pass cognitive defences, including those resulting from automization of skilled behavior.

The problems of knowledge acquisition have been clearly stated:

> "Knowledge acquisition is a bottleneck in the construction of expert systems. The knowledge engineer's job is to act as a go-between to help an expert build a system. Since the knowledge engineer has far less knowledge of the domain than the expert, however, communication problems impede the process of transferring expertise into a program. The vocabulary initially used by the expert to talk about the domain with a novice is often inadequate for problem-solving; thus the knowledge engineer and expert must work together to extend and refine it. One of the most difficult aspects of the knowledge engineer's task is helping the expert to structure the domain knowledge, to identify and formalize the domain concepts." (Hayes-Roth, Waterman & Lenat 1983)

This paper is concerned with interactive computer aids to the knowledge engineer based on a model of the person that has strong systemic and psychological foundations (Shaw & Gaines 1986, Mancuso & Shaw 1988). Personal Construct Psychology (Kelly 1955, Shaw 1980) has been widely used as a basis for developing methods of knowledge acquisition from experts in a given domain (Shaw & Gaines 1983, Boose 1984, Diederich, Ruhmann & May 1987, Shaw 1988). Personal Construct Psychology is a psychology of the individual and many of its applications emphasize the idiosynchratic nature of conceptual systems. However, it is also a psychology of the individual interacting with the world and embedded in society (Shaw 1985). It encompasses shared concepts and conceptual systems, and their generation through experience. In particular it encompasses those systems that are so widely shared and so significant that they are construed as **knowledge**, and treated as having an existence virtually independent of their carriers.

Entity-attribute, or repertory grid, methodologies based on Personal Construct Psychology allow a significant part of the conceptual systems of experts to be elicited through interactive interviewing techniques. Knowledge Support System Zero (KSS0) supports entity and attribute elicitation, clustering and inductive rule generation in addition to other techniques. It is written in Pascal and runs on the Apple Macintosh family of computers to provide a highly interactive and graphic knowledge acquisition environment. At the heart of KSS0 is an object-oriented knowledge base in which knowledge is formally represented as a multiple-inheritance digraph of classes, objects and properties.

AN OUTLINE OF KNOWLEDGE SUPPORT SYSTEM ZERO

The main tools in KSS0 are shown in Figure 1:

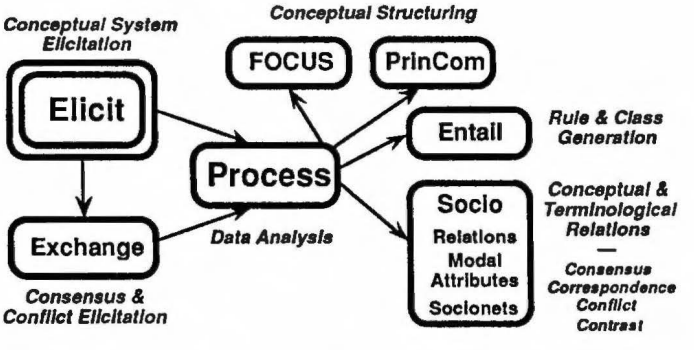

Fig.1 Some tools in Knowledge Support System Zero.

- **Elicit** accepts specifications of entities within a domain and provides an interactive graphical elicitation environment within which the experts can distinguish entities to derive their attributes. The resultant class is continuously analyzed to provide feedback prompting the expert to enter further entities and attributes.
- **Exchange** allows interactive exchange and comparison of entities and attributes from multiple experts in a domain.
- **FOCUS** hierarchically clusters entities and attributes within a domain prompting the experts to add higher-level entities structuring the domain.
- **PrinCom** spatially clusters entities and attributes within a domain prompting the experts to add higher-level entities structuring the domain.
- **Entail** induces logical entailments enabling the attributes of an element, or the evaluations of a decision-making situation in a domain, to be derived from other attributes.

- **Socio** compares the structures for the same domain generated by different experts, or the same expert at different times or from varying perspectives.

Part of the interaction from a study with a small group of geographers (Shaw & Woodward 1988) is used to give a flavour of **Elicit**. Figure 2 shows the common spatial mapping techniques agreed on by all the geographers, and is the start of one of Expert 2's elicitation sessions. She selects **Triple**, and three techniques are shown, where she is asked to click the mouse on the one which is different from the other two. She clicks on *Probability mapping* and elicits the attribute *local — global* which is shown in Figure 3 with some techniques already rated, some waiting in a list on the left, and *proximal mapping* being dragged on to the attribute bar. Both the attribute labels and the techniques can be edited any time, and also the placing of the techniques. Figure 4 shows two matched attributes, with both sets of ratings shown, so that they can be compared. Again, any one is moveable if the expert wants to adjust anything.

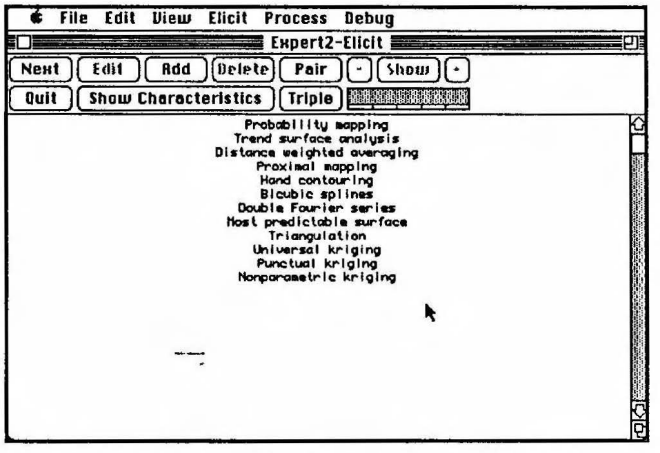

Figure 2. KSS0 screen showing the entities used by the geographers.

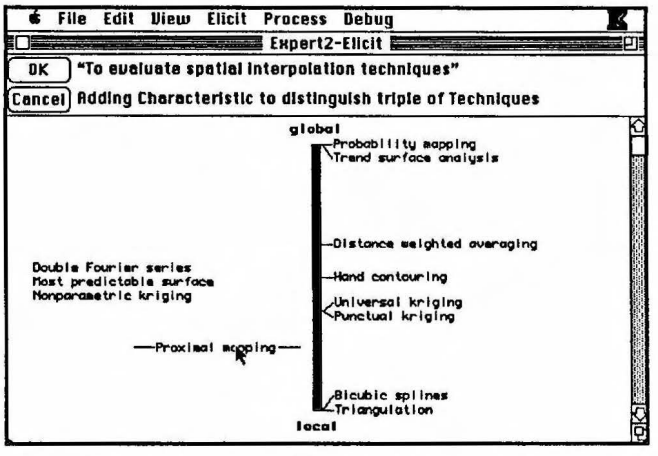

Figure 3. KSS0 showing click and drag elicitation.

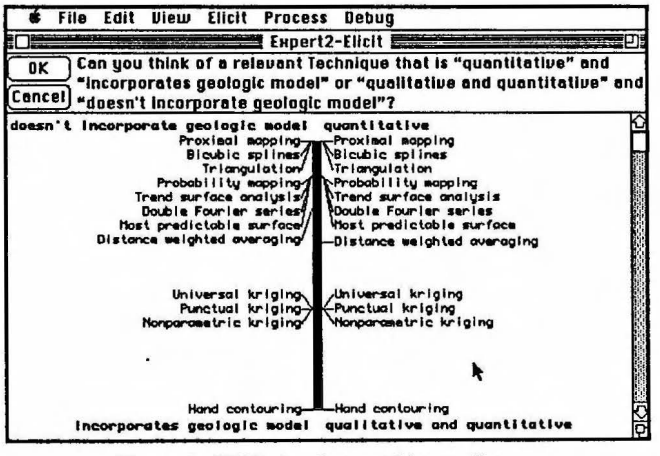

Figure 4. KSS0 showing matching attributes.

Techniques may also be matched, as shown in the screen in Figure 5. The technique at the top has a marker on each attribute sticking up, and the one at the bottom a marker sticking down. Again, any marker is moveable if the expert wants to change anything. Figure 6 shows the FOCUS clustering of the final grid. As can be seen on the attribute tree at the top right, there are three clusters at 75%, and one attribute which is not part of any cluster. From the bottom right tree of techniques, it can be seen that the one most different from the others is *hand contouring*. Many other conclusions can be drawn from this diagram, but it is sufficient here just to give a flavour of what the expert experienced in using KSS0.

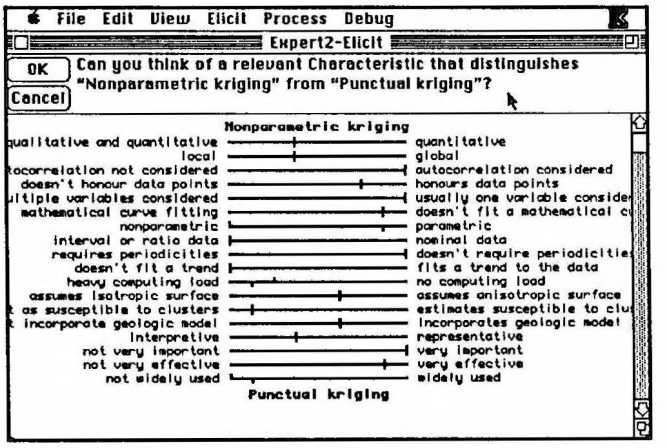

Figure 5. KSS0 showing matching techniques.

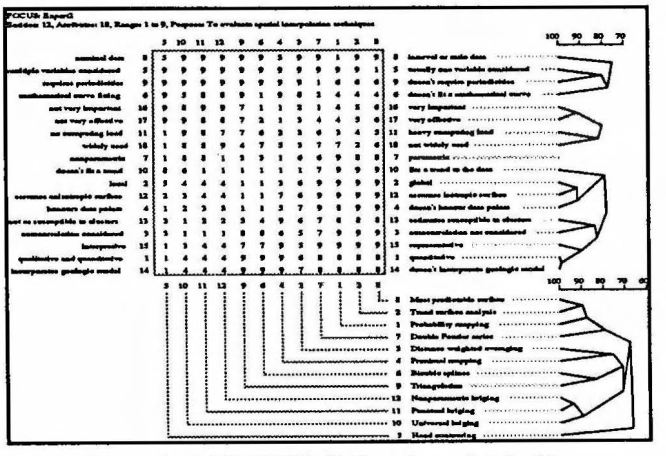

Figure 6. KSS0 FOCUS display of completed grid.

Exchange grids are used for the measurement of understanding and agreement between either two experts or on two occasions (Shaw 1980). To do this two people each elicit a grid in an area of common knowledge or experience. Each may choose his own entities independently of the other, and elicit and rate his attributes quite separately. Each then can **Exchange** his grid, that is use the other's entities and attributes but not the rating values. This is then completed by the other expert. By comparing pairs of these grids it is possible to map the extent of overlap of the agreement and understanding between the two experts. The **Exchange** procedure allows several experts to be aware of and explore the meaning of each other's terminology in the domain. The experts can then understand and extend their own thinking and problem-solving capabilities with ideas from other experts. They are able to see the relationship of their points of view to those of others; explore differing terminology for the same attributes; become aware of differing attributes having the same terminology; extend their own conceptual systems with those of others; provide others with attributes they have found valuable; and explore a problem-solving domain using the full group resources.

The **Process** facility allows single and multiple grids to be analysed. The **FOCUS** algorithm is a distance-based hierarchical cluster analysis technique that sorts the entities and attributes into a linear order such that those closest together in the space are also closest together in the order. It has the advantage in presentation that the sorting is used only to re-present the original grid re-organized by the neighbourness of attributes and elements. It is left to the user to construe his own personal meaning into the result and confirm this directly in terms of the original data. The tree diagrams show the entity

and attribute clusters and are imposed on the re-sorted original grid data (Shaw 1980). The **PrinCom** algorithm is another distance-based cluster analysis using standard principal component analysis. This analysis has been used widely because it gives a visually meaningful map of some of the relations between entities and attributes, that can be used to gauge the major dimensions along which an expert is making distinctions.

The **Entail** algorithm is a logical analysis of the conceptual system taking the expert's distinctions to be fuzzy predicates (Zadeh 1972, Gaines 1976). The program derives asymmetric implications between the attribute poles so that one can infer how a new entity might be placed on one attribute given how it is placed on others (Gaines and Shaw 1981). It can also provide rules for input to an expert system shell (Gaines and Shaw 1986). **Entail** gives a dependency analysis of the attributes in a grid by deriving significant logical entailments consistent with the data. From a clustering point of view this analysis is significant because it can show up one-way relations that may be missed by distance-based clustering techniques. However, in the present context it is more significant that the entailments may be treated as inference rules to be used in an expert system.

The **Socio** program provides facilities for comparing and contrasting multiple sources of expertise. It is an extension of SOCIOGRIDS (Shaw 1980) for deriving socionets and mode attributes from groups of individuals construing the same class of elements. Its objective is to take different classes representing the same domain and compare them for their structure, showing the similarities and differences. It may be regarded as the implementation of a simple form of analogical reasoning. If the grids may have the same entities and attributes but possibly differing values **Socio** analyzes the matches between the entities and the attributes in the grids according to the values, and shows those entities and attributes that are similar and those which are different. A typical application is to see whether experts agree on the definitions of classes by asking them to separately fill in the values for a domain definition **Exchanged** between them. If they agree then it is **consensus**, and if they disagree it is **conflict**. If the grids have different attributes but the same entities **Socio** analyzes the matches between the attributes in the grids, and for each attribute in the original shows the closest matching attribute in the other class. A typical application is to see whether experts are using different terminologies for the same attributes by asking them to define attributes separately and fill in the values for a domain defined through an agreed set of elements. Here, **correspondence** between entities or attributes can be identified. If there is no similarity in either terminology or the use of the attributes, this is **contrast**. Figure 7 shows the four possibilities which can occur in this intersection of the experts' conceptual structures (Shaw & Gaines 1989).

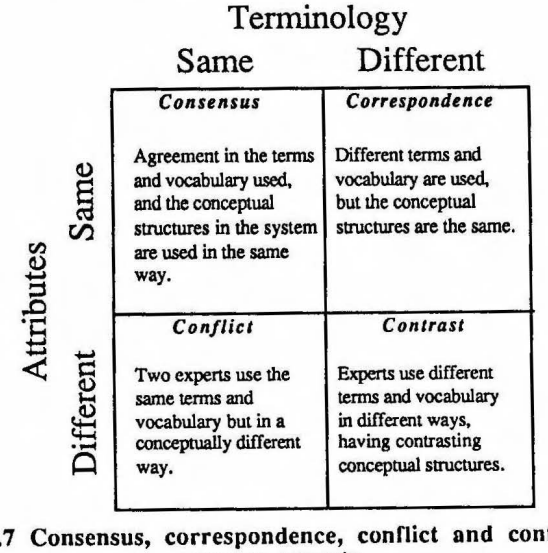

Fig.7 Consensus, correspondence, conflict and contrast among experts.

CONSENSUS, CORRESPONDENCE, CONFLICT AND CONTRAST

This section gives an example of the methodology in action using data from the study of geographers specializing in mapping techniques previously cited (Shaw & Woodward 1988).

The **Socio** analysis of an exchange grid, in which expert B has filled in the values for a class defined by entities and attributes elicited from expert A, compared with the original, sorts the attributes so that the most similar are at the top of the list. It is the drawn as a **difference grid** where rating values (in this case 1 to 5) for expert B's ratings of expert A's entities on his attributes are subtracted from expert A's similar rating values respectively. Figure 8 shows this with the entities and attributes about which they agree the most in the top right corner, shown by no difference or a difference of only 1; and those with most disagreement towards the bottom left, shown by the maximum difference of 4 or a large difference of 3. It can be seen, for example, that the attribute, *requires no model—requires model* shows high disagreement, and looking further into the elicited data it can be seen that expert A thinks that *probability mapping requires model*, whereas expert B thinks that *probability mapping requires NO model*. On inquiring into this, the explanation given was couched in terms of what one actually means by the term "model", indicating the conflicting use of terminology.

The match values are shown on the right of the grid, and taking a value of 80 or above out of 100 as consensus and 70 or below as conflict, it can be seen that there is clear consensus on the top four attributes, clear conflict on the lower five, and uncertainty about the remaining three.

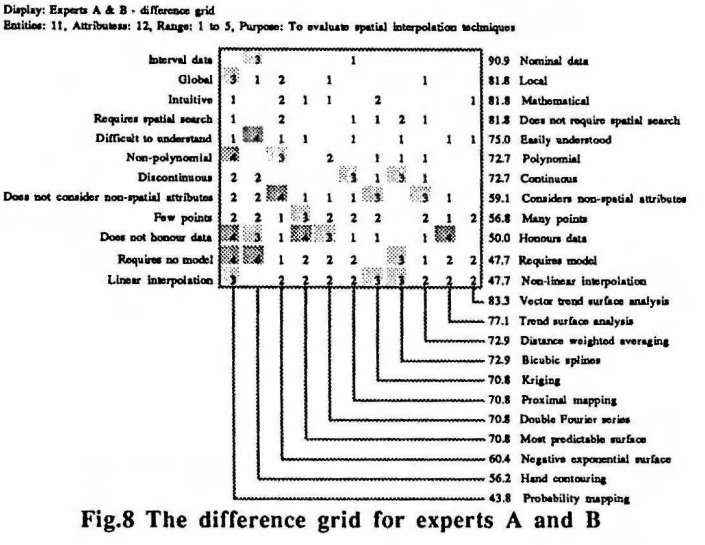

Fig.8 The difference grid for experts A and B

From the other comparison in which expert B and expert A have different attributes it can be seen that:

- The first or highest match has a level of 88.5 out of a 100. That is, both experts are using the attribute *local-global* in the same way. This is an example of correspondence. However, it is not an interesting one because the terms used are the same and it is effectively arising from a consensus.
- For the second attribute, when expert A uses the term *low-level-data—high-level data,* expert B is using the term *nominal data—interval or ratio data*. This shows a difference in terminology which can be interpreted as their levels of abstraction being different in their construing of this topic. This illustrates the two experts having attributes in correspondence.
- The third match again shows a correspondence that can be interpreted as arising from consensus, with both experts using the attribute *does not honour data points—honours data points* in the same way. Note that this showed up as conflict in Figure 8, probably reflecting that, in this study, the methodology was more complex and the exchange grids from which Figure 8 derives were elicited and discussed in the early stages of the study *before* those from which the correspondence data derives.
- The fourth match shows a correspondence between *short-distance autocorrelation—long-distance autocorrelation* and *local—global*. Notice that *local—global* used by expert B was also used in the first match indicating that expert A has two attributes *short-distance autocorrelation—long-distance autocorrelation* and *local—global* which are used similarly to each other but with different terminology, whereas expert B has only one. In fact, looking on to the seventh and eleventh matches, it can be seen that expert A has two more attributes *discontinuous—continuous* and *does not require a priori model—requires a priori model* which correspond to expert B's single attribute

local—global. This shows a differences in richness of concepts not necessarily making new distinctions in the class so far defined by the entities.

- The eighth match again shows correspondence. It shows the attribute *heavy computing load—no computing load* is being used by expert B to correspond to *mathematically complex—mathematically simple* used by expert A. We can interpret this as a difference in terminology corresponding to a correlation in the real-world.

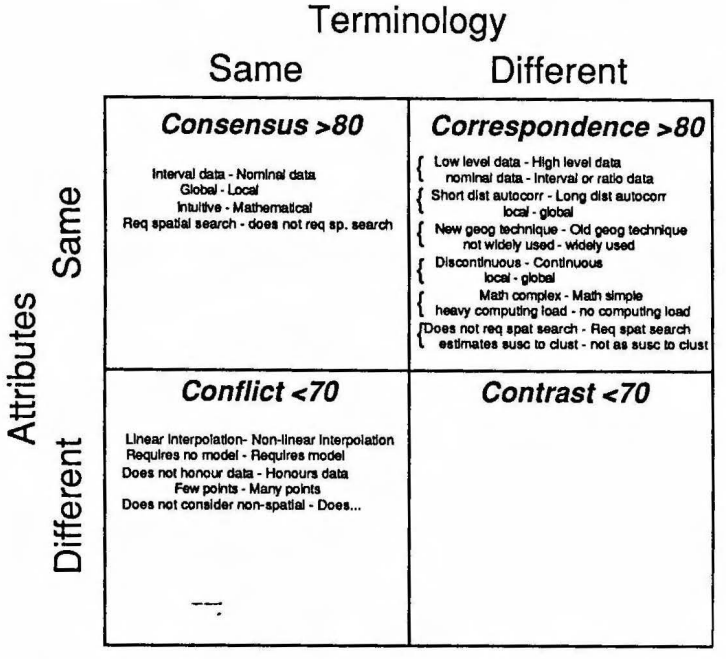

Fig.9 Consensus, correspondence, conflict and contrast from the geography data

Figure 9 shows each of these attributes put into the appropriate quadrant of Figure 7. There is no significant example of contrast in this data, possibly because the two experts work very closely together. Such examples do arise in a full analysis of the three experts in the original study.

When a number of grids representing the same domain are available, **Socio** also provides two other forms of analysis. The first is that it tries to derive "modal" entities or attributes that reflect a consensus among the experts by extracting those which occur as highly matched entities or attributes across the majority of classes. A typical application is to reach consensus on critical concepts that are associated with a rich vocabulary at differing levels of abstraction. The other is that it derives a set of socionets showing the degree to which each expert is able to make the same distinctions as another expert, even if they use different terminology. A typical application is to validate the knowledge acquisition process by determining whether the structure derived conforms with known relations between the experts. This data is shown in Shaw and Gaines (1989).

CONCLUSIONS

KSS0 is a knowledge support system providing an integrated set of tools for knowledge acquisition. **Elicit** provides facilities for eliciting the important dimensions of an expert's thinking on a topic; **Exchange** extends this to share entities and attributes between experts and elicit differences in perspective and terminology as well as disagreements on the topic. **Socio** processes results from several experts to reveal the similarities and differences in the concept systems of different experts, or the same experts at different times, construing a domain defined through common entities or attributes. It can be used to focus discussion between experts on those differences between them which require resolution, enabling them to classify them in terms of differing terminologies, levels of abstraction, disagreements, and so on. It provides a framework for identifying consensus, correspondence, conflict and contrast in a knowledge acquisition system with multiple experts.

Note that the derivation of consensual, corresponding, conflicting and contrasting attributes is completely algorithmic, based solely on the data in the grids. This derivation is done by a computer program, not a knowledge engineer, and its basis can be demonstrated clearly to the experts through computer output such as the difference grid of Figure 8. Thus, there are no opinons being expressed about the correctness of the use of the attributes and terminology, that the differences highlighted are 'right' or 'wrong.' It is open to the experts to consider, discuss and explain these differences, changing or retaining them as they wish. Conflicts can be retained in the final system if desired by tagging classes, objects and rules with the sources from which they derive.

The methodology promotes the full exploration of the conceptual framework of a domain of expertise by encouraging experts to operate in a "brain-storming" mode as a group, using differing viewpoints to develop a rich framework. It avoids social pressures forcing an invalid consensus by providing objective analysis of separately elicited conceptual systems.

ACKNOWLEDGEMENTS

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