An exploration of expertise of knowledge workers: towards a definition of the universe of discourse for knowledge acquisition

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Abstract. *Knowledge systems development and use have been significantly encumbered by the difficulties of eliciting and formalizing the expertise upon which knowledge workers rely. This paper approaches the problem from an examination of the knowledge competencies of knowledge workers in order to define a universe of discourse for knowledge elicitation. It outlines two categories and several types of knowledge that could serve as the foundations for the development of a theory of expertise.*

Keywords: expert systems, information systems, knowledge acquisitions, systems development.

INTRODUCTION

The past several years have seen a shift in the focus from data-intensive to knowledge-intensive computer applications. The quest for competitive advantage, the 'promise of smart machines' and the increasing number of low-cost knowledge systems shells (KSSs) have all given impetus to this trend. The key to successful knowledge systems development (KSD), however, lies in the ability of knowledge engineers (KE) to elicit and represent the wide variety of knowledge upon which knowledge workers rely during problem solving. Although much effort has been spent on techniques and methods for acquiring knowledge from knowledge workers in the application domain, not much has been done to formally define a universe of discourse (UoD) for knowledge acquisition, or to identify appropriate theoretical foundations for these methods. As knowledge engineers confront the knowledge acquisition (KA) problem in every new application, it becomes apparent that more research is needed to improve our understanding about the nature of the UoD of KA. Although KSSs have advanced, in many ways resembling fourth generation languages, development efficiency remains low. Reasonable-sized systems still require many man-years of effort (Butler & Corter, 1986; Waterman, 1986).

The principal purpose of this paper is to stimulate enquiry towards the development of a *theory of expertise*. Current theory in KSD has given primacy to *facts*, *rules* and their *relationships*, which can be elicited from the mind of the knowledge worker. It is believed that all relevant facts and rules pertaining to a problem domain can be captured in a large store of particulars. These particulars contain references to all the entities about which the KS must 'know' in addition to predicates and relationships that describe the relevant properties of these entities and rules for reasoning about them.

Experience in KSD has shown that it is fallacious to think of a knowledge worker's expertise as consisting of static cognitive structures that can be neatly divided into rules, facts and their relationships. KS developers have come to recognize that other types of knowledge embedded in the social context of the problem domain play an important role in problem solving. But because of the difficulties of identifying and representing them, they have been classified as implicit knowledge and relegated to *terra incognito*. Problems in KS applications have, however, led to doubt as to whether limiting the focus of knowledge acquisition to the facts and rules that the knowledge worker can articulate is sufficient for developing effective knowledge systems. It has become clear that a theory of expertise or knowledge-in-work is fundamental to the advancement of the state-of-the-art of knowledge systems development and use. Although some researchers have postulated various typologies of knowledge (Agnew *et al.*, 1986; Wielinga & Breuker, 1986; Johnson *et al.*, 1987; Slatter, 1990; King & McAulay, 1991), no theory of knowledge-in-work has emerged, and few discussions have articulated the importance of the *social context* of problem solving in knowledge work (Suchman, 1983, 1987; Hagglund, 1989; West, 1990, 1992). We believe that it is important to understand the role of the social context in knowledge work and problem solving, as this could assist KEs in defining the UoD of knowledge acquisition and identifying the possibilities and limitations of proposed knowledge systems. This paper outlines the basic idea of the social context of problem solving, and briefly discusses its importance to knowledge acquisition for KS development. By focusing on these kinds of issues, this paper hopes to make some headway on the difficult task of developing a theory of expertise.

PROBLEMS AND PUZZLES IN KNOWLEDGE ACQUISITION

Current methods of knowledge acquisition are well discussed in the literature; however, a brief review of those in common usage is important to the present discussion. These are (a) interviews, (b) verbal protocol analysis, (c) scenario or case analysis and (d) prototyping. Several computer-supported knowledge acquisition tools (CSKAs) are also emerging. Empirical results on studies of these systems have been disappointing. For a discussion of some of these tools see Shaw (1980, 1984), Shaw & Gaines (1983), Boose (1984), Bennett (1985) and Greene & Smith (1987).

Practice and research with these and other methods have revealed six fundamental problems that must be examined and understood if progress is to be made towards a general theory of knowledge acquisition. In order to prepare the way for the broader discussion of this paper, a brief description of these problems is necessary:

1 *Experts are unable to articulate all of their expertise.* As an example, consider a rich literature written by chess masters that still does not tell us how to play chess at the grand-master level.

2 *The inability of knowledge engineers to elicit implicit knowledge.* There might be a larger amount of diffuse background knowledge ('prudence and wisdom') which influences knowledge worker judgements that cannot be easily decomposed into a set of particular facts and rules. For example, Kant (1964) in his theory of knowledge distinguished between rules of skill, rules of prudence and categorical rules. It appears that current KA focuses primarily on rules of skill and thereby assumes that other rules are unimportant.

3 *Inconsistency and incompleteness in knowledge workers' descriptions of their problem-solving strategies.* Knowledge workers might fall back on naive theories about human problem solving and thereby distort or corrupt their records. Why should the judgements of knowledge workers in, say, law or finance be reliable about their own thinking processes?

4 *The inability of knowledge engineers to understand and capture the knowledge worker's openness of problem solving to invention and novel applications of knowledge.* The key to a particular problem solution might come from accidental or systematic interference with another case. Hence, the environment in which knowledge workers live and work can exert significant stimuli and influences. The key to understanding the sources of creativity might be in the environment and to look in the knowledge of worker's minds to look in the wrong place.

5 *The best knowledge workers are too busy or simply cannot be bothered to cooperate in KA.* Further, more knowledge is a power base for individuals and for various communities in society. Therefore, knowledge workers might consider their knowledge secret or, even more subtly, they might mislead the knowledge engineers in order to maintain the privileges of their positions. How could a knowledge engineer discover that superficial or outdated knowledge was being offered?

6 *Experts notoriously disagree*. If knowledge systems are developed reflecting the disagreement and knowledge workers, how should a tie be broken? Whose knowledge should count?

To see the real magnitude of the KA problem, it is helpful to analyse the difficulties of a particular method in more detail. For this, we choose 'concurrent protocol analysis'. Verbal protocols are obtained by the 'thinking aloud method'. This approach has had a long history in psychological research on human problem solving and, therefore, a good chance to prove itself (Duncker, 1945; Newell *et al.*, 1959). The thinking aloud method has been proposed to overcome the following difficulty: if knowledge workers are asked to focus on their mental processes, and possibly try to record them, this detracts from their concentration. If merely asked to speak to themselves, while enacting their problem-solving routines, they are much less distracted. In fact, some people naturally speak to themselves when working on a difficult problem. By recording the subjects' thoughts and keeping the knowledge workers' working notes, a record of the whole process is created and can be analysed (Newell & Simon, 1972). The practice of recording outlined above is different from self-reports. Thus it helps to overcome the problem of corruption of the record referred to under item 1. If protocols for different knowledge workers are kept (a very laborious process), typical thought patterns might become evident (see Fig. 1).

Ericcson & Simon (1980) found, however, that verbal reports obtained in this way are incomplete, inaccurate and inconsistent. Klein (1971), who used them to develop a knowledge system for poker, found that this method puts an immense burden of interpretation on the researcher. There is no reason to believe that the knowledge engineer will correctly understand and interpret the sketchy record of a knowledge worker's problem solving. After all, the knowledge engineer is not a colleague in the knowledge worker's field. Key steps may have been omitted, because knowledge workers are unable to articulate them. As an example, consider merely the simplest case in which the knowledge is available somewhere in long-term memory and can be articulated in principle, but the knowledge worker fails to retrieve it. An interpretation problem also exists because the knowledge engineer may be unable to perceive the subtle pointers to variations in problem-solving strategies that signal the inventiveness and creativeness of the expert. The best knowledge workers are those who know when to break or modify their rules. The knowledge engineer looking for rules may abstract from the deviations in order to arrive at rules. A further complication arises in that knowledge workers learn during problem solving but are unable to articulate this new knowledge.

How is it that some very interesting results were achieved by relying on the thinking aloud method? An examination of the cases in which the thinking aloud method and protocol analysis have worked well reveals that these were mostly 'closed-world' problems. Examples are logical puzzles or simple theorem-proving exercises. The researcher knew different solution strategies that helped to make sense of the protocol record. In addition, the problem could be well bounded, such as spectral analysis or diagnosis of bacterial infections, and there was a small number of data to work on. It could, therefore, be stated very succinctly: all the information that was needed to solve the problem could be given with the initial problem description as a puzzle. There was little opportunity for the problem to evolve and be fundamentally redefined. A large, well-understood scientific base existed for solving the problem. None of this applies when developing KS for management, law, tax accounting, investment strategy, product engineering, and so forth. These are 'open-world' types of applications in which social context becomes important. This is not a new idea in information processing systems — several researchers have made this argument before, for example Suchman (1983, 1987), Suchman and Wynn (1984), Winograd and Flores (1986) and Ciborra and Lanzara (1989). However, knowledge engineers have generally disregarded the social context as an element of the UoD of knowledge acquisition.

THE SOCIAL CONTEXT OF PROBLEM SOLVING

Every problem situation in which a knowledge worker engages is situated within a context of social institutions and structural conditions, that is, the social context. For the knowledge worker, the social context provides a reservoir of institutional knowledge, 'rules and resources', which guides the performance of problem-solving routines (Parsons, 1951; Giddens, 1976; Thompson, 1981; Suchman, 1983, 1987). The social context is composed of: (1) lifeworld, (2) organization and (3) problem domain.

The *lifeworld* is the taken-for-granted intersubject reality shared by members of a given organization. It consists of the interpretations of all personal work experiences as well as the sedimentations of the collective experiences of members of the organization. It is a reservoir of 'organizational knowledge', that is culture, belief systems, myth, value orientation, and so on. Without these, common beliefs about social interaction and role expectations within the organization could not be supported.

Part of the lifeworld, and lifeworld schema, is cognitively assimilated and biographically articulated by the knowledge worker. This schema serves as a filter through which the knowledge worker apprehends and interprets organizational reality. It comprises a set of preinterpreted scripts of symbolic knowledge — patterns of meaning about organization symbols, icons, relationships and structures, and taken-for-granted implicit background knowledge sedimented from past experiences and socialization. Although this stock of knowledge is not a logically specified and articulated system, as is scientific knowledge, this does not fundamentally compromise its validity. It remains an unproblematic totality of self-evidences about the social context from problem situation to problem situation.

The *organization*, at one level of abstraction, is the sphere of human interaction oriented by rules and complexes of role expectations. However, with regard to action constitutive knowledge, it may also be defined as a set of collective goals, procedures, norms, values and resources upon which every knowledge worker depends during problem solving (Parsons, 1951).

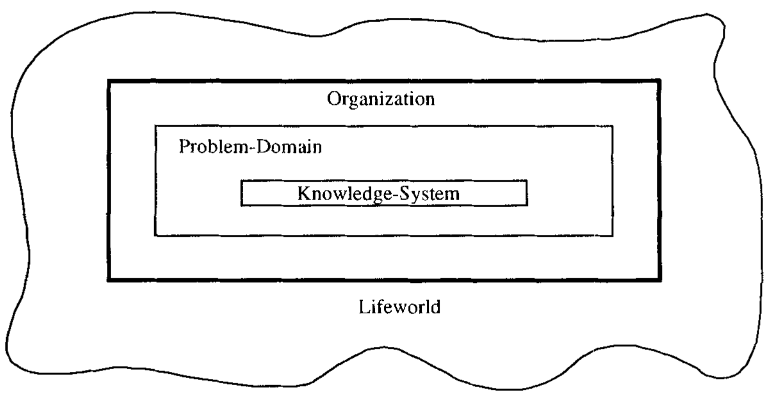

Figure 1. The sphere of intervention of knowledge systems.

The *problem domain* is the immediate domain of the problem of interest. Every problem domain that a knowledge worker encounters already has meaning within the social context. It is the symbolic knowledge of the social context that facilitates recognition and understanding of the problem of interest. In this regard, knowledge systems ought not to be conceptualized as neutral rational problem-solving machines finding objectively correct solutions in a social vacuum. They are just as embedded in the social context as the knowledge workers they support. It should be clear from the above that the social context is a fundamental aspect of the UoD of knowledge acquisition. It contributes to the pragmatics and general competence of the knowledge worker and the knowledge system.

PROBLEM SOLVING AND EXPERTISE

The question 'Who is an expert?' is still largely undecided. Knowledge systems development practice holds that any knowledge worker who has been around long enough, and made all the mistakes that can be made in the field, is an expert. Although the importance of experience cannot be denied, it is those insights that the knowledge worker has distilled from training and work experience, and applies effectively in sense making and problem framing and solving, that are important. Research has suggested that this expertise is organized as schemas of complex interrelated problem domain scripts (Schank & Abelson, 1977). Knowledge workers often enact these schemas without conscious awareness, attention or forethought. These schemas are built from experiences with previous problem situations (Schutz & Luckmann, 1973; Fiske & Taylor, 1984); Gioia, 1984). They are repertoires of knowledge used to impose structure and meaning upon otherwise ambiguous information about the problem domain. They help the knowledge worker simplify and effectively manage information about complex problems and their social environmental characteristics. These scripts also serve as filters for determining what aspects of the problem domain are relevant and for the construction of meaning for the problem of interest.

It has been argued that the expertise of knowledge workers can be classified into two categories of knowledge schemas (see Fig. 2): (1) explicit foreground knowledge (EFK) and (2) implicit background knowledge (IBK). This paper does not intend to suggest that this is an exhaustive list. The fundamental idea is to start a dialogue that focuses attention on the narrow bias of the usual facts/rules distinction, and to make it clear that more subtle typologies of knowledge need to be considered in KS development. These particular categories and types of knowledge have been chosen at this time because of their prior recognition by other scholars, in particular as reported in the literature on the theory of knowledge and epistemology. In addition, there is evidence in the literature that shows the influence of each type of knowledge on the problem-solving behaviour exhibited by knowledge workers. Each of these schemas is composed of a set of goal-directed scripts that contain functional subparts for problem identification, problem framing and problem solving. The problem identification component comprises knowledge of the salient features by which a class of problems could be identified and categorized; in contrast, problem framing and solution parts comprise the appropriate

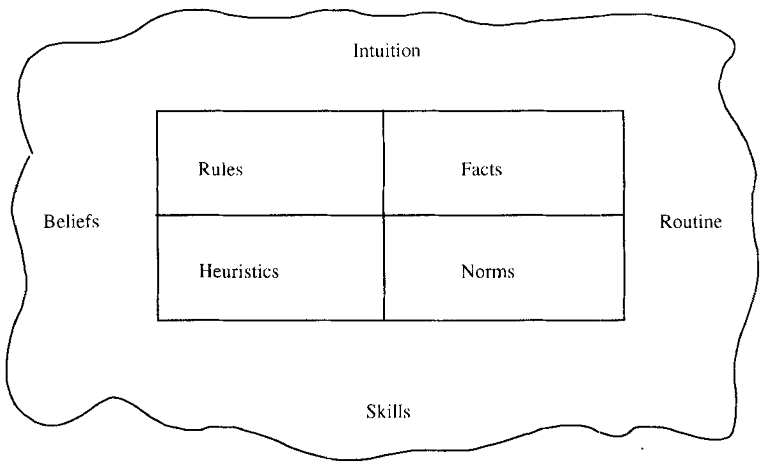

Figure 2. Action constitutive knowledge.

strategies for making sense of the context of the problem domain and solution procedures for analysing and debugging the problems.

According to Shiffrin & Schneider (1977), knowledge workers operate in two modes during problem solving: automatic and controlled. In *automatic* mode, they enact IBK schemas to deal with unproblematic situations and can simultaneously carry out several activities without conscious effort. In *controlled* mode they activate both IBK and EFK schemas to deal with novel or difficult situations that require planning, debugging and the development of new action plans in order to bring about a solution. The major problem, however, is the inability of the knowledge worker to provide step-by-step recall of action plans of IBK scripts.

EXPLICIT FOREGROUND KNOWLEDGE

Explicit foreground knowledge consists of facts, rules, formal heuristics and social norms that the knowledge worker has consciously assimilated from socialization and can, in principle, articulate or demand. This category of knowledge has also been referred to as present-at-hand knowledge (Winograd & Flores, 1986). *Facts* are well-formed assertions about the prevailing state of affairs relevant to the problem domain. Facts need not have empirical validity, but they must have social validity. *Rules* and *formal heuristics* are hypotheses of action that have been rationalized and logically articulated from scientific theories. Rules and heuristics give rise to expectations of achieving specific outcomes when appropriate action plans are executed (Mattessich, 1978). *Social norms* are shared beliefs that guide and determine human behaviour within the organizational context. They are concerned with how persons ought to act in given situations. Although norms operate as 'organizational facts', they need not have empirical validity or voracity. To know and understand a norm is to know what decision choices are consistent with it. Norms are in a constant state of flux as a result of evolution in organization norm systems. Two types of norms are important here: prescriptive and directive.

1 *Prescriptive* norms deal with modes of ethical conduct. These often take the form of prohibitions and advice that delimit the sphere of operation of the expert.

2 *Directive* norms define the means to be used in attaining specific goals. They are concerned with efficient and correct accomplishment of action plans. Experts must have explicit understanding of norms if they are to take effective action in the organizational context.

IMPLICIT BACKGROUND KNOWLEDGE

Implicit background knowledge, on the other hand, consists of inarticulable routine, beliefs and tacit and intuitive knowledge distilled from experience. These types of knowledge can be applied unreflectingly during problem solving (Schutz & Luckmann, 1973). Further, they are essentially those interpretations of previous work experiences of the knowledge worker that have passed 'the tests' of repeated application and do not need to be re-examined with regard to their validity. They serve as subjective reference schema that enable knowledge workers to interpret the problem domain and to define goals for problem-solving activity. Although this stock of knowledge is not a logically articulated or explicitly represented system, this does not fundamentally compromise its validity. It remains 'in the background' as the expert moves from problem domain to problem domain. Three important types of implicit background knowledge are:

(a) routine or instinctive knowledge,
(b) tacit knowledge or skills,
(c) intuitive knowledge or knowledge of recipes.

Routine or *instinctive* knowledge presents knowledge workers with definitive solutions to the problem domain which are organized in the flow of work experiences without their having to be conscious of them. Essentially, it is the understanding of solutions to everyday occurrences or puzzles that were once problematic but have been definitively solved by some inarticulable skill or art. This means that routine/instinctive knowledge can subordinate and coordinate or even dominate EFK during problem solving without the knowledge worker being conscious of it. The effectiveness of this type of knowledge becomes subjectively certain to the knowledge worker through repeated success under application, and becomes sedimented in the form of taken-for-granted, ready-at-hand solutions scripts for specific problems.

Routine/instinctive knowledge was formulated by Chomsky (1957). According to Chomsky, individuals have knowledge competence of language beyond that which they are able to describe, but which they use in everyday linguistic action. In support of this argument, he points to young children who are able to effectively construct proper linguistic utterances, albeit with some difficulty, far beyond their experience or explicit knowledge of the language. The primary characteristic of this type of knowledge is that it is unexplainable but is expressed in the form of accomplishing a result without prior experience or training that is in any way commensurate with the accomplishment.

Tacit knowledge is those inarticulable skills that knowledge workers know they have distilled from prior experience and consciously apply in problem solving. Polanyi (1958) defines tacit knowledge as that which can only be transferred by exemplars. (An exemplar is a recorded approach that has been applied successfully to a difficult and evasive problem.) Take, for example, the case of teaching someone how to swim or to ride a bicycle. It has been noted that no one is able to explain to a student how to ride a bicycle. The only pedagogical technique useful in this situation is demonstration. The teacher must get onto the vehicle and show the student how it is done. Another good example outlined by Polanyi (1958) is the problem of teaching certain mathematics and physics problem-solving strategies that cannot be explained except via exemplars that have been developed by astute and brilliant researchers in the field (Kuhn, 1970). Such exemplars then enter the textbook literature as solved puzzles and students acquire the tacit knowledge by trying to solve them and comparing their solution path with that of the master. The importance of tacit knowledge is also recognized in systems development when insisting on case work in systems analysis and design courses.

The third type is *intuitive knowledge* or *knowledge of recipes*. This type of knowledge is in operation when, faced with a new problem situation, an *ad hoc* theory is constructed to help interpret the situation and develop solution strategies. A good example of this is 'seat of the pants' management decision making by a manager who is not interested in developing general theories or any scientific testing as proposed by scientific management theories. Instead, the manager has a large 'bag of tricks' and wishes to construct an explanation of the problem situation before taking action. Often, the manager considers the 'bag of tricks' to be valid *a priori*, which is confirmed by on-the-job experience. Interest is confined mainly to scanning the problem space for certain recognizable patterns or key features to confirm the manager's 'gut feeling'.

The original formal notion of intuitive knowledge can be traced back to Spinoza (1930, 1958) who believed that people have an intuitive faculty and when presented for the first time with certain types of propositions can immediately recognize them to be true. In support of his argument, Spinoza offered the postulates of Euclidean geometry as evidence for such a faculty. The power of intuitive knowledge can be seen at work in every type of problem-solving activity from simple everyday problems to the construction of scientific hypotheses for testing. Ideally, this type of knowledge encompasses a corpus of well-tried and accepted concepts (bag of tricks) of the experienced problem solver. Moreover, it is likely to be unstructured and highly selective, unless reflected upon in a conscious manner by the individual.

IMPLICATIONS FOR FURTHER RESEARCH

Implications for knowledge systems development and use derived from the above analysis are as follows:

1 The definition of the UoD of knowledge acquisition must be extended beyond the cognitive structures of the knowledge workers. Although several researchers have pointed out that the social context of the problem domain plays an important role in intelligent problem solving (Bateman, 1985; Stamper, 1985; Winograd & Flores, 1986; Suchman, 1987), it has not yet been given serious consideration in KS development methodologies. The social context of the problem domain has implications for why the knowledge worker selects certain action plans and rejects other seemingly applicable ones during problem solving. By focusing on relevant aspects of the social context, the knowledge engineer could engage the knowledge worker in a dialogue about appropriate organizational norms which may be important to the solution space of the problem. Techniques are needed which could assist knowledge engineers with this type of inquiry and analysis.

2 A clearer understanding of the implications of each type of knowledge for problem solving is important for identifying the limits of current KS technology. The significance of each type might vary between different types of problem-solving activity and application areas. How exactly they might vary can only be demonstrated by case studies that detail the *knowledge profile* by which certain classes of problems are handled. Research on developing and testing a tool for classifying applications areas based on the above knowledge typology is in progress (see Ngwenyama *et al.*, 1990). Such a tool could assist knowledge engineers in making decisions concerning the feasibility of proposed KS applications and in selecting knowledge acquisition methods and techniques appropriate to the proposed application.

3 Understanding which knowledge acquisition techniques are effective for eliciting which type of knowledge, and what types of knowledge cannot be extracted and represented in computer-processable form, can significantly advance the process towards developing comprehensive knowledge acquisition methodologies. This would require extensive field tests of techniques covering a wide range of real-world problems. Understanding what types of knowledge are inaccessible could also help the knowledge engineer define the limits of the problem-solving capacity of the KS. It may also be possible to program this self-knowledge into the KS, so that it can inform users when they present it with a problem that is beyond its problem-solving capacity. This issue was addressed for a special class of intelligent information systems by Kaula (1990); however, a more general solution to the problem needs to be developed.

4 There is also the need to extend or reconceptualize inference strategies to deal with problem solving with other types of knowledge beyond rules and facts. Research has shown that the standard mechanism of knowledge-based system shells is limited only to problems that can be defined in terms of backward and forward chaining (Kobsa, 1984; Naylor, 1986). A new inference strategy has been developed and implemented for open intelligent information systems (see Kaula, 1990; Kaula & Ngwenyama, 1990). But research is required to generalize it to other applications.

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