Knowledge Acquisition Using Structured Interviewing: An Empirical Investigation

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ABSTRACT: The knowledge acquisition problem endures as a bottleneck in the construction of expert system knowledge bases. Despite the recent proliferation of techniques and the availability of more sophisticated methods for this task, the interview technique continues to be widely used, especially in business domains. This paper reports the results of an experiment conducted to compare the unstructured knowledge acquisition interview with a specific type of structured knowledge acquisition interview. Structure for the interview was provided by a domain model of the business decision-making activity that attempted to capture the subjective and qualitative aspects of decision making. Senior managers from industry served as the subjects in the experiment. The interview technique was evaluated along efficiency and effectiveness dimensions. Results indicate improved performance with the structured interviewing method.

KEY WORDS AND PHRASES: Expert systems, knowledge acquisition, structured interviewing.

1. Introduction

KNOWLEDGE ACQUISITION (KA) IS THE PROCESS OF EXTRACTING domain-specific problem-solving expertise from a knowledge source and representing it in machine manipulable form [10]. The term is generally used in the context of expert systems development, where such knowledge is acquired from a human expert. The knowledge then forms the basis for a technical artifact that can reasonably simulate expert problem-solving behavior in the domain under consideration. There has recently been a proliferation of techniques for eliciting expert knowledge. This phenomenon is attributable to the realization that a prime cause for the slow diffusion of expert

systems technology is the knowledge acquisition bottleneck—the task is time intensive, cumbersome, and poorly understood [4, 21]. While current methods may be adequate in experimental settings, wider commercial application depends upon the development of structured techniques that make the technology economically viable [21]. Despite two decades of experience in developing expert systems, the knowledge acquisition problem remains an enduring issue with academics and practitioners alike.

There are a number of inherent difficulties with the process of knowledge acquisition from human experts. The major limiting factor is what Johnson [26] calls the "paradox of expertise." As individuals become more skilled at performing certain tasks, they become less aware of the cognitive processes involved in their performance. The paradox of expertise renders it difficult for experts to articulate their problem-solving strategies effectively as they are themselves not fully cognizant of the steps involved. Further, expertise is typically acquired over a long period of time through an exposure to a wide variety of problem situations. The limited storage capacity of attentional memory hinders the ability of the expert to recall situations in the past that form an essential part of his/her expertise [40, 43]. Consequently, the knowledge elicited is limited to that which is readily available to conscious introspection by the expert at the time of inquiry. When asked to describe their methods of problem solving, experts tend to provide "reconstructed" versions of their reasoning, articulating the explicit, reportable components and overlooking the more subjective parts [3, 26]. These difficulties are compounded by the fact that there are currently very few experienced knowledge engineers available to perform this ill-structured task [31].

Buchanan et al. first systematically addressed the problem of KA as a specific area of concern [10]. Since then, other authors have suggested a number of techniques, strategies, and approaches to the elicitation of expert knowledge. We refer the reader to the literature that contains several comprehensive reviews and typologies of the large number of knowledge acquisition techniques available [4, 18, 20, 22, 32].

In spite of its many limitations and the availability of more sophisticated techniques, the interview still remains the most widely used method for knowledge acquisition. The interview is conceptually simple for the knowledge engineer and expert to comprehend. In addition, it is a familiar and natural task [42]. Because of the popularity of the interview technique, a knowledge engineer's ability to interview effectively becomes a significant factor in determining the completeness, accuracy, and reliability of the collected knowledge [41]. However, even though the efficiency of the knowledge engineer's method directly influences the expenditure of resources for knowledge-base development, knowledge engineers rarely undergo training in practical interviewing methods [41].

This research was motivated by a need to develop more effective structured interviewing methods to extract knowledge specifically for managerial decision problems. We report the results of an experiment conducted to compare the efficacy of two types of interviewing techniques for knowledge elicitation—the unstructured interview and the structured interview. Our objectives were twofold: first, we tried to develop a meaningful structure for a KA interview related to the acquisition of business

knowledge, and second, we addressed the issue of the practical applicability of different types of interviews.

We investigated a very specific type of structured interview, where structure to the interview was provided by a model of the decision-making activity. Both novice and experienced knowledge engineers elicited knowledge from experts in a business domain. Evaluation of the structured interviewing technique was performed along efficiency and effectiveness dimensions. Results showed that novice knowledge engineers using the structured interview technique performed better than those using the unstructured technique on a variety of response variables. The experiment also indicated that the structured technique can help novice knowledge engineers perform at a comparable level with experienced knowledge engineers.

The next section briefly reviews the literature on interviewing in general and for knowledge elicitation in particular. Section 3 presents the model that was used for structuring the knowledge acquisition interview, highlighting the theoretical basis for the model in cognitive psychology. Subsequent sections describe the experiment, the research hypotheses, the results, and the implications of these results. The final section summarizes the limitations of the study and provides some avenues for future research.

2. Interviewing as a Technique for Knowledge Acquisition

THE INTERVIEW IS THE MOST PREVALENT TECHNIQUE for eliciting knowledge from experts [9, 30, 42]. While the word "interview" has many different connotations, depending on the discipline that is defining the term [15, 37], there is general agreement that the basic purpose of an interview is effective communication. The major advantages of the interview technique are its ability to assist in issue clarification through repeated probing by the interviewer and the fact that it provides for immediate feedback. The communication and counseling literatures emphasize that an interview can prove to be an invaluable information-gathering tool, particularly in situations when beliefs, feelings, and attitudes that are undetectable through writing are to be elicited [15, 27, 37].

Interviews fall along a continuum. At one end is the unstructured interview, characterized by asking "rather general questions about the field, tolerating digressions, tape recording everything and hoping to extract useful information from the transcript" [42]. Unstructured interviews can be useful information-gathering techniques in the early stages of knowledge acquisition, when issue exploration and a broad familiarity with the domain is desired [32]. The lack of organization in an unstructured interview, however, frequently results in the method being extremely time consuming and inefficient for knowledge elicitation [41]. At the other end of the spectrum is the structured, goal-oriented interview that promotes a systematic exchange of information by imposing an organization on the communication between the knowledge engineer and the expert. The structured interview has many advantages over its unstructured counterpart, including its ability to extract specific information that is easy to review, interpret, and integrate, and the extent to which it forces the expert not to diverge from the goals of the knowledge acquisition session [31]. Both unstructured

and structured interviews may be enhanced through the use of probes, i.e., follow-up questions to a specific part of an answer. While probing in an unstructured interview deals primarily with issue clarification, in a structured interview a probe may be used by the knowledge engineer to extract specific information relating to the structure [32].

In practice, interviews are rarely completely unstructured or completely structured. Even within a structured interview, it is often desirable to allow for a certain degree of flexibility. In a rigidly structured interview, the knowledge provided by the expert may be an outcome of the pressure of questioning rather than a correct description of behavior [8]. Neither technique can be used as the sole method for knowledge acquisition, since they are useful at different stages in the process.

The fact that unstructured introspection alone is not a reliable way of obtaining organized descriptions of complex cognitive processes led researchers to search for better ways to structure a KA interview [41]. KA interviews can be structured in various ways and to varying degrees. Effective structuring of a knowledge acquisition interview requires some type of model of the domain knowledge to be elicited. That is, the knowledge engineer must have some a priori understanding of how problems are solved and how knowledge is organized in the domain under consideration [42]. From a theoretical perspective, the domain model provides a template against which elicited descriptions of problem-solving behavior can be compared. From a pragmatic perspective, the model helps structure and focus the communication between the knowledge engineer and the expert. Domain models currently in use include heuristic classification [12] and specific versions of the classification model for medical and electronic diagnosis.

Our interest was in using a model of the general domain of managerial decision making to structure the knowledge acquisition interview. Because these decision-making domains exhibit characteristics that are unique, none of the models used in prior research for expert system development could be successfully transported and applied. Previous studies note that building an expert system to produce a diagnosis, the way a medical expert does, poses a very different set of problems than designing an expert system to replicate some aspect of managerial decision making [6, 13, 14, 16]. KA strategies thus far have addressed expert systems that operate in narrow, specialized technical domains where a single expert or group of experts makes a judgment in relative isolation and where the expertise is essentially *transportable* across situations [2].

We used a model of the decision-making activity to develop an interviewing technique for knowledge acquisition. The model provided structure to a knowledge acquisition interview, and we conducted an empirical study to rate its efficacy. The following section describes the model underlying the interview method.

3. A Domain Model for Business Decisions

DECISIONS MADE BY MANAGERS CAN BE OF SEVERAL TYPES and can occur at various stages in the organizational hierarchy. In practice, it is extremely difficult to construct a single model that describes such a wide range of possible decision-making scenarios

[5]. However, prior research has noted that, despite dissimilarities in domain-specific knowledge, there are some key similarities among these processes that can be used to construct a general model [14, 17]. These similarities are manifest in the context and environment of managerial decision making.

The premise underlying the model is that the organizational *context* is a crucial factor in determining the actions of individuals making decisions on its behalf [16, 36]. Isenberg, among others, has highlighted the importance of organizational and interpersonal processes on managerial thinking and decision making [23]. Any domain model for managerial decision making must encapsulate knowledge about the specific decision-making task under consideration, such as planning, allocating human resources, etc. This model must also explicitly consider the influence of the *context* and *environment* on decisions [16]. While current practices in expert systems development are adequate for capturing problem-specific information, their ability to extract such context-sensitive knowledge is unclear [3]. Providing the interviewer with contextual information is particularly important, because experts who articulate "reconstructed" [26] versions of their reasoning tend to overlook the subjective and tacit considerations [3].

Many researchers have attempted to identify the components of the context or environment that influence decision-making behavior. Duncan developed an empirically derived list of internal and external components that directly influence decision behavior (see Appendix) [17]. We believe that Duncan's characterization provides a sound model for structuring the knowledge acquisition interaction. The categories are application independent and broad enough to provide knowledge about a wide range of decision-making situations, even though the extent to which a given factor affects a particular decision may vary.

We suggest that a domain model which attempts to capture the relationship between decision behavior and the organizational context is essential for two major reasons. First, research in managerial decision making highlights the impact of organizational subjectivity and value systems on decisions [36]. Second, for the development of expert systems, the impact of contextual factors on the decision-making process has to be captured and modeled *explicitly*. Incomplete information was not a serious problem for management information and decision support systems, as users were the decision makers themselves and able to incorporate contextual information as needed. Expert systems are often intended for novice users who may be unable to assess the relevance of information excluded from the system adequately [3]. However, most of the literature on knowledge acquisition does not consider the role of the organizational context explicitly [19, 25]. This again is a result of current ES applications being restricted to fields such as medical diagnosis, oil exploration, etc.

The model used to describe the impact of the organizational context on decisions can also assist in overcoming some of the cognitive limitations on the expert's ability to communicate the more subjective and tacit components of the decision-making process [40, 43]. Empirical studies of human long-term memory have indicated that, although the long-term memory store for knowledge, events, etc. is virtually unlimited, retrieval from this memory store is strongly affected by the contents of short-term or

attentional memory [40, 43]. Simon [35] describes the pattern recognition abilities of human experts in game-playing contexts, and Isenberg corroborates these findings in a study of senior managers [23]. Thus, an individual's processes of recall are affected by the information presented at the time an event is to be recalled. The provision of appropriate, relevant cues can assist in the recall of past decision information [24, 40, 43].

The KA technique we suggest uses Duncan's categories to structure a knowledge acquisition interview and to act as cues for a recall of past decisions. This type of structuring should focus the questioning of the knowledge engineer and reduce extraction time. Further, the process of "cued recall," with the domain model providing the cues, should result in a more *effective* knowledge acquisition session. The experiment conducted to confirm these and related questions and its results are described in the following section.

4. Empirical Analysis of the Technique

FEW PREVIOUS STUDIES DISCUSS THE COMPARATIVE EVALUATION OF KA techniques. Burton et al. note that most studies of the effectiveness of KA techniques are either case oriented, or are an attempt to match KA techniques with types of knowledge on theoretical grounds [11]. A notable exception is the laboratory experiment they performed and reported in the same article, which compares four knowledge acquisition techniques: the formal interview, protocol analysis, goal decomposition, and multidimensional scaling along a variety of performance related issues [11].

We undertook a field experiment to compare the performance of the unstructured interview with the type of structured interview described previously. While the literature presents sufficient anecdotal evidence to suggest that structured interviewing is more useful than unstructured interviewing [31, 41], we have not found any empirical work confirming that statement. In order to keep the study tractable, comparison with other interviewing techniques (e.g., teachback [25] and tutorial [19] interviews) was not included in the experiment. We evaluated the performance of the structured interviewing technique along two primary dimensions—efficiency and effectiveness, with hypotheses relating to each of these. The dimensions were operationalized through the response variables described below.

A knowledge acquisition methodology must be efficient in its utilization of scarce resources, particularly if that resource is the valuable time of an expert. As a construct, KA efficiency has been defined as the number of informative propositions generated per task minute [22]. In the context of knowledge-base development, informative propositions include criteria and rules. A criterion is any concept that directly or indirectly *influences* the decision under consideration. The identification of relevant criteria is crucial, because an important task in attempting to model a decision-making process is to isolate variables that affect it. Rules specify the *relationships* between these variables and the eventual outcome of the decision-making process—the decisions that are made. Thus, the efficiency dimension was measured by the following dependent variables: (1) number of criteria identified as germane in the knowledge

acquisition session per page of interview transcript, and (2) number of rules identified. Note that the first dependent measure takes into account the operationalization problem of length of interview session and accounts for the information generated in a unit amount of interaction.

Any knowledge acquisition methodology must assist the expert in overcoming cognitive limitations on the articulation of problem-solving knowledge. These limitations manifest themselves both in the inability of the expert to explicate tacit and subjective knowledge [3] and in the difficulties experienced in successfully transferring relevant information from long-term to short-term memory [40]. The experiment operationalized effectiveness of KA through three response variables: (1) the proportion of tacit and subjective criteria extracted, (2) the extent to which the methodology assisted the expert in recalling unusual situations in the problem domain that had occurred in the past and were not available to immediate recall, and (3) the extent to which the methodology helped the expert in anticipating future decision-making scenarios. We felt that the third measure was important because an expert system developed solely on the basis of situations that have occurred in the past will tend to become obsolete in a very short period of time. Thus, an important component of KA is to ask the expert to "look ahead" and anticipate hypothetical future decision-making situations, so that the system can be an adaptive artifact also.

Research Hypotheses

The hypothesis that structured interviewing would focus the dialogue into meaningful channels, and hence generate a larger amount of information in a given amount of time, was stated as follows:

HM1: The structured interviewing technique is a more efficient procedure for extracting knowledge than unstructured interviewing.

The organizational dissemination of any new technology requires a cadre of individuals who are qualified and trained to develop applications using it. A shortage of experienced knowledge engineers is one of the primary reasons for the slow diffusion of expert system technology. Because there appears to be little consensus in the literature on appropriate qualifications for knowledge engineers [33, 38, 39], we investigated the extent to which the methodology proved to be an aid to inexperienced knowledge engineers with the following hypothesis:

HM2: The use of the structured interviewing technique will allow novice knowledge engineers to perform better than they would using the unstructured interview.

Managerial decision making, as a process, is distinct from decision making in other domains because it tends to be more subjective in nature [14]. Note that this subjectivity is not necessarily individual subjectivity, but rather subjectivity that arises from organizational concerns and is implicitly or explicitly manifest in the choices made [36]. Qualitative and subjective factors help make a reasoning model underlying an expert system richer by incorporating the effect of the individual on the decision-mak-

ing process. The contribution of the methodology in capturing these factors was tested through the following hypothesis:

HM3: The structured interviewing technique will extract more subjective and qualitative knowledge from experts than the unstructured interview.

In accordance with Tulving's [40] encoding specificity theory, the study hypothesized that the use of predefined contextual components to cue the expert would serve two major functions: (1) helping the expert recall any exceptional situations that may have occurred in the past but are not available to immediate recall, and (2) helping the expert anticipate how these factors may play a role in the future. Each expert completed a 5-point Likert-scaled questionnaire to assess the effect of the interaction with the knowledge engineer on his/her recall and anticipatory scenario construction. These data were used to test the following hypothesis:

HM4: The structured interviewing technique will provide the expert more assistance in recall and anticipation than the unstructured interview.

Research Design

The experiment employed a completely randomized single-factor research design with three treatment levels [28]. The three treatment levels were: (1) knowledge elicitation by novice knowledge engineers using an unstructured interviewing technique (group 1); (2) knowledge elicitation by novice knowledge engineers with training in the use of Duncan's components to structure the interview (group 2); and (3) knowledge elicitation by experienced knowledge engineers using an unstructured interviewing technique (group 3). Group 1 was the control group, the second group was the experimental group, and the third group was the reference group for evaluating the performance of the methodology. A 2×2 factorial design, with type of interview and experience of knowledge engineer as the two factors might have been more appropriate. One of the major problems faced by an experiment of this nature, and in expert system construction in general, is the availability of experienced knowledge engineers. For this reason, we found a 2×2 factorial design to be unfeasible.

Sample and Treatment Administrators

The experimental task was a capital budgeting/resource allocation decision. This decision is strategic and unstructured in nature and qualitative factors play an important role in it [7]. Thirty expert practitioners from industry who were responsible for this decision were included in the sample and randomly assigned to the three groups. Their organizations consider these managers as being "good, experienced" decision makers and would select them as sources of knowledge, were the organization to develop an expert system for this problem domain. Background data on the experts who participated in the experiment are summarized in Table 1.

Treatment administrators for the first two groups (i.e., the novice knowledge

engineers) were graduate business students with similar backgrounds in terms of work experience and exposure to the capital budgeting/resource allocation decision. We surveyed the students in order to ensure comparability along the following dimensions: (1) selected individuals had to have the same amount of prior knowledge about the decision situation—i.e., familiarity with the problem in an academic sense, but no practitioner experience of it, and (2) selected interviewers had to have comparable experience in counseling/interviewing type professions.

Experienced knowledge engineers administered the third treatment level. The following criteria were used to select individuals as knowledge engineers in the third group: (1) MIS practitioners who have had experience with knowledge engineering for at least one expert system project, or (2) practicing systems analysts with at least three years of experience in systems analysis. While there are no empirical studies equating the skills of systems analysts to those of knowledge engineers, previous research has noted that crucial qualities possessed by both sets of individuals (specifically, the ability to communicate effectively) appear to be similar [18]. The average number of years of experience possessed by the systems analysts who participated in the study was over five years.

The physical setting of the experiment was the actual work environment of the domain expert in all but two of the cases. Knowledge engineers were guaranteed to have the exclusive attention of the expert without any interruptions during the KA session. The interaction between the knowledge engineers and the experts was audiotaped and subsequently transcribed and analyzed using the analytic scheme discussed in the next section.

Treatment administrators for the first two groups were randomly assigned to the "novice" and "novice with methodology" treatments. All three groups of knowledge engineers gained familiarity with domain terminology and concepts through an audiotape describing the form of a generic resource allocation decision and the factors that are typically taken into consideration. The "novice with methodology" group was trained in structuring the interview by constructing questions in each one of the environmental categories identified by Duncan [17]. A sample of the components and questions relating to them is provided in Figure 1. This group allowed the experts first to describe their decision-making process and then asked them to reflect on Duncan's components. Knowledge engineers asked specific questions related to the effect of Duncan's components on the resource allocation decision. Experts were informed that the interview would last for a maximum of one and a half hours, but knowledge engineers could conclude it earlier if they had no more questions to ask. All interviews were completed within the prescribed time limit.

Generation of Response Variables and Statistical Analyses

Two secondary observation methods generated response variables: a content analysis of the interview transcripts and an instrument to measure recall and anticipation. Content analysis allows replicable and objective inferences to be made from textual materials [29]. Figure 2 shows the identification of rules in the interview transcripts

Problem description:

Projects are submitted by various individuals in the organization for management's approval, and management has to decide which of these projects will be selected for eventual funding. Because resources are typically limited, this decision is made by taking into consideration a variety of qualitative and quantitative factors that represent organizational objectives and priorities.

The following questions illustrate the use of some of Duncan's environmental components to construct interview questions in the above described problem domain.

1. **Organizational personnel component**
   - (a) **Education and technological background**

     Does the individual proposing the project possess the required educational and technological background to complete the project successfully?
   - (b) **Previous technological and managerial skill**

     What is the individual's track record like? Have similar projects been undertaken in the past? If so, what were the outcomes?
   - (c) **Individual member's involvement and commitment to attaining system's goals**

     How motivated is the project proposer? Is he/she sensitive to organizational objectives?
   - (d) **Interpersonal behavior styles**

     Does the project require the proposer to possess special interpersonal skills, i.e., is the project one that will entail a certain amount of group decision making and delegation of work? Is there a match between the proposer's management style and the nature of the project?

Note: Duncan's environmental components are indicated in bold.

Figure 1. A Sampling of Duncan's Components and Interview Questions

through a content-analytic unitization scheme. Similar schemes that explicated the definitions of each of the variables of interest (criteria and qualitative criteria) were developed. The data were coded by two independent coders to ensure inter-judge coding reliability, which was above 90 percent for all the unitization schemes used. Krippendorf's percentage agreement test was used as the index of reliability [29].

Even though random assignment was employed in the experiment, Table 1 indicates the disparity among the experts in terms of their experience in the problem domain. In order to avoid confounding, the primary statistical model employed was analysis of covariance, with the number of years of experience of the experts in the problem domain as the covariate. For the response variables where the overall F-statistic was significant ($\alpha = 0.05$), Scheffe's [34] multiple comparisons procedure isolated where the differences lay.

Summary of Results

Tables 2, 3, and 4 summarize the results of the experiment. Table 2 outlines the p-value for the overall F-test for each of the response variables. Table 3 summarizes the multiple comparisons procedure, while Table 4 outlines the hypotheses, the response variables used to test them, and the results of the test. Hypotheses HM1 and HM3 were confirmed at $\alpha = .05$, HM2 was accepted on three response variables and rejected on two ($\alpha = .05$), and HM4 was rejected at $\alpha = .05$.

Identification of Rules in Interview Transcripts

00189 A: Earlier I alluded to this ranking process that we have with
00190 ranks from one to six- not a perfect match- but it ended up
00191 that we were only able to fund those projects ranked one,
00192 two, three, and like, half of the fours. So the ones that didn't
00193 make it....
00194 Q: What was the criteria then? What gave something a one
00195 versus a two or three?
00196 A: One was something that was safety related[1]. Two was
00197 imminent failure with long term consequences[2].
00198 Q: What would be a six then?
00199 A: Something with a positive benefit to cost ratio but
00200 payback greater than one year[3]. It was either a three or a
00201 four, I'm not sure exactly, if a project had a positive
00202 benefit to cost ratio, it was considered a good project and if
00203 it paid itself off in one year then it became a four[4]. So
00204 that ended up being one that would get done. In essence we
00205 did not do the ones- you know they might be good projects,
00206 but they would have a longer term benefit and they did not
00207 make the cut list.

Rules identified using the rule unitization scheme are underlined.

Figure 2. Identification of Rules in Interview Transcripts

[1] Rule 1 [2] Rule 2 [3] Rule 3 [4] Rule 4

Discussion

Hypothesis HM1 compared the methodology with the unstructured interviewing technique on the basis of its efficiency in extracting knowledge. Efficiency of knowledge acquisition can contribute to both a reduction in system development time and better resource utilization. Recall that efficiency was operationalized as number of criteria per unit content and number of rules generated in a KA session. This hypothesis was accepted (Table 2). Test results indicate that the methodology did perform significantly better in terms of efficiency, as the mean number of criteria per unit content and the mean number of rules extracted by group 2 were significantly larger than the mean number extracted by the other two groups. Further, the fact that a larger number of rules were extracted using the structured interview suggests that the technique achieved the objective of eliciting more focused, specific information.

Table 1. Sample Characteristics

no. of years in capital budgeting	title	organization
5	vice president and treasurer	equipment leasing
25	vice president	manufacturing
10	vice president	manufacturing
7	division controller	pharmaceutical
30	president and CEO	service
6	treasurer	manufacturing
20	chairman and CEO	consumer durables
25	vice president	manufacturing
10	manager	manufacturing
25	assistant vice president	health care
15	regional manager	consumer products
3	vice president	manufacturing
12	vice president	data processing
7	vice president	data processing and R&D
7	vice president	utility
15	manager	R&D
5	manager	utility
6	manager	financial services
14	manager	manufacturing
10	director	data processing
10	director	pharmaceutical
10	manager	manufacturing
10	director	manufacturing
3	vice president	manufacturing
8	vice president and treasurer	holding company
5	manager	manufacturing
15	vice president	manufacturing
6	executive vice president and CEO	promotional trade assn.
10	president and CEO	manufacturing
10	chairman and CEO	service

Hypothesis HM2 compared the effectiveness and efficiency of knowledge engineers using unstructured and structured interviews. This hypothesis was tested by an intergroup comparison for groups 1 and 2 on all response variables where the overall F-test indicated a difference. Efficiency was defined as mentioned previously, while effectiveness was measured by the proportion of qualitative criteria and the extent to which the technique helped in recall and anticipation. An objective in developing a knowledge acquisition methodology was to provide a mechanism whereby inexperienced knowledge engineers could perform at better levels with minimal training. In addition, the training provided to them was explicit and replicable, as opposed to skills acquired "on the job."

The results of the multiple comparisons procedure support the claim that structured interviewing can improve the *efficiency* of inexperienced knowledge engineers (see Table 3). Further, HM2 was accepted ($\alpha = 0.05$) for the response variable qualitative criteria as a proportion of total criteria. This result suggests that the structured

Table 2. Summary Results of Analysis of Covariance Procedure

variable	*p*-value
rules	0.0297
criteria per unit content	0.0132
qualitative criteria/total	0.0008
recall	0.0754
anticipation	0.2970

Table 3. Summary Results of Multiple Comparisons Procedure

	group means			group comparisons		
variable	g_1	g_2	g_3	*1 and 2*	*2 and 3*	*1 and 3*
rules	5.2	9.9	6.1	Y $g_2 > g_1$	Y $g_2 > g_3$	N
criteria per unit content	2.98	3.84	3.16	Y $g_2 > g_1$	Y $g_2 > g_3$	N
qualitative criteria/total	0.299	0.419	0.328	Y $g_2 > g_1$	Y $g_2 > g_3$	N

Y = significant comparison ($\alpha = 0.05$)
N = non-significant comparison
g_1 = group 1 (novice with unstructured)
g_2 = group 2 (novice with structured)
g_3 = group 3 (experienced with unstructured)

interviewing technique improved the effectiveness of knowledge acquisition by novice knowledge engineers along one dimension by extracting a richer domain model.

A model of expert behavior must be robust enough to capture the subjective and qualitative aspects of expert reasoning, a description that underlies hypothesis HM3. Subjective and qualitative factors are of particular importance in managerial decision-making domains [14, 16]. HM3 was accepted ($\alpha = 0.05$). Test results suggest that the methodology did assist knowledge engineers in acquiring significantly more subjective knowledge. In fact, novice knowledge engineers with training in the interview technique performed better than even the experienced knowledge engineers (see Tables 2 and 3). An implication of this result is that the use of a domain model that incorporates subjective factors for structuring a knowledge acquisition interview can help experts overcome some difficulties associated with articulating tacit knowledge.

Hypothesis HM4 was constructed to compare the structured interviewing technique with the unstructured interview on the basis of its ability to assist experts in recalling past decisions and anticipating future decision-making scenarios. The recall and anticipation response variables were both self-reported by the experts. HM4 was rejected for both response variables, with *p*-values of 0.0754 and 0.2970, respectively (see Table 2). While there were no statistically significant differences in the percep-

Table 4. Summary Results of Hypothesis Tests

hypothesis	tested by	accepted ($\alpha = 0.05$)
HM1	criteria per unit content	Y
	rules	Y
HM2	criteria per unit content	Y
	rules	Y
	qualitative criteria/total	Y
	recall	N
	anticipation	N
HM3	qualitative criteria/total	Y
HM4	recall	N
	anticipation	N

tions of the experts in all three groups for the recall variable, the mean scores for group 2 were larger than the mean scores for the other two groups (3.4, 4.3, and 3.3 for groups 1, 2, and 3, respectively).

Though test results do not reveal the structured interview as enhancing expert recall and anticipation significantly, we feel that this may be an outcome of the nature of the experiment. Knowledge was elicited in a single session, and this was the first meeting between the knowledge engineer and the expert. It is likely that recall and anticipation would be impacted more in subsequent knowledge acquisition sessions.

Perhaps the most interesting aspect of the results is evident in Table 3. There were no statistically significant differences between the performances of groups 1 and 3 (novice and experienced knowledge engineers), while group 2 (novice with methodology) performed consistently better than the others on all the response variables for which the overall *F*-test indicated a difference. While it is difficult to draw an unequivocal conclusion from these findings, the data seem to suggest that regardless of the background and prior experience of the knowledge engineer, the unstructured interviewing technique performs more poorly vis-à-vis the type of structured interview under investigation. Though this result is not new, it empirically confirms the literature that extols the benefits of the structured interview [31, 41].

In summary, more relevant criteria per unit content, rules, and qualitative criteria were generated using the methodology vis-à-vis the unstructured interview, suggesting that the structured interview contributes to the efficiency of KA and, to some extent, to its effectiveness. Though the number of rules generated in the knowledge acquisition sessions in the experiment was not large, that is not necessarily a limitation. Once relevant criteria have been identified, rules to address these criteria can be extracted by further probing in subsequent knowledge acquisition sessions.

Our experimentation does not conclusively show if a structured interview is inherently more useful than an unstructured one. The experiment does indicate that the use of a domain model for structuring knowledge acquisition can prove to be a worthwhile exercise. This result is intuitively obvious, and future research efforts will attempt to develop richer domain models.

External Validity and Limitations

The study has three limitations to its generalizability. First, the experts constitute a convenience, rather than a random sample, even though random assignment was employed in assigning them to groups. Second, the structured interview was used in only one specific problem domain, resource allocation. The results of the study apply only to samples and tasks that conform to the sample and the task used here. Third, we used some systems analysts as surrogates for experienced knowledge engineers. This was seen as unavoidable, since expert systems technology is still in its incipient stages and very few people have undergone formal training in it.

This experiment did not compare the knowledge elicited from the experts with some predefined "gold standard," as has been done in the past [11], for two reasons. First, the domain does not lend itself to the development of an objective set of knowledge that would be applicable in all situations. The subjectivity in this domain precludes the possibility of comparing the knowledge generated to some prescriptive standard. Second, the objective of the knowledge acquisition exercise was to extract each expert's procedural rationality [35] where the organization viewed the expert as being a competent decision maker. The commitment and willingness of the experts to participate suggest that they had no motivation to provide incorrect information to the knowledge engineer.

Finally, we investigated the performance of the technique in a single knowledge acquisition session. The results do not indicate how well the technique would perform in subsequent sessions, or, if it would, in fact, prove effective throughout the development cycle of an expert system.

5. Conclusion

KNOWLEDGE ACQUISITION IS A MAJOR IMPEDIMENT in the development of expert systems. The focus of our own and other expert systems research has been on making the knowledge acquisition process more effective and manageable. This study has proposed a knowledge acquisition methodology and has tested it empirically. The methodology consists of a structured interviewing technique, and this paper describes the results of an experiment comparing the structured interview technique with unstructured interviewing.

Results indicate that the specific type of structured interview examined performs better than the unstructured interview along a variety of response variables. Specifically, the structured interviewing technique increased the efficiency of knowledge acquisition, and extracted more subjective and qualitative knowledge than the unstructured technique. Further, the technique allowed novice knowledge engineers to perform at a level that was comparable to experienced knowledge engineers. The results suggest that using a domain model such as Duncan's [17] to structure a knowledge acquisition interview can prove to be a valuable exercise.

Besides a few notable exceptions [11], the literature contains few references to research that has attempted to compare experimentally the efficacy of different

knowledge acquisition techniques. In our view, such experimentation is imperative before an organization can make choices as to what techniques it will include in its portfolio and the type of training that should be provided to its knowledge engineers. These techniques are relevant for the development of expert systems, and have potential applicability in information requirements determination for conventional computer-based information systems [1]. Research in the area of KA must proceed simultaneously along two paths, both in the development of new techniques that are measurably "better" than existing ones, and in the intercomparison of existing techniques.

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APPENDIX: Factors and Components Comprising the Organization's Internal and External Environment

INTERNAL ENVIRONMENT

(1) Organizational Personnel Component

- (a) Educational and technological background and skills
- (b) Previous technological and managerial skill
- (c) Individual member's involvement and commitment to attaining system's goals
- (d) Interpersonal behavior styles
- (e) Availability of manpower for utilization within the system

(2) Organizational Functional and Staff Units Component

- (a) Technological characteristics of organizational units
- (b) Interdependance of organizational units in carrying out their objectives
- (c) Intra-unit conflict among organizational functional and staff units
- (d) Inter-unit conflict among organizational functional and staff units

(3) Organizational Level Component

- (a) Organizational objectives and goals
- (b) Integrative process integrating individuals and groups into contributing maximally to attaining organizational goals
- (c) Nature of organization's product service

EXTERNAL ENVIRONMENT

(1) Customer Component

- (a) Distributors of product or service
- (b) Actual users of product or service

(2) Suppliers Component

- (a) New materials suppliers
- (b) Equipment suppliers
- (c) Product parts suppliers
- (d) Labor supply

(3) Competitor Component

- (a) Competitors for suppliers
- (b) Competitors for customers

(4) Socio-political Component

- (a) Governmental regulatory control over the industry
- (b) Public political attitude towards industry and its particular product
- (c) Relationship with trade unions with jurisdiction in the organization

(5) Technological Component

- (a) Meeting new technological requirements of own industry and related industries in production of product or service
- (b) Improving and developing new products by implementing new technological advances in the industry

Source: Duncan [17].