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A STUDY OF THE PROPERTIES OF THE ACCESSIBLE KNOWLEDGE OF FOUR NOVICE AUDITORS DURING PERFORMANCE OF A FIELD TASK

By

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ABSTRACT

The level of an auditor's expertise during performance of a field task is directly related to the accessibility of that auditor's knowledge. This paper presents initial findings from a multi-part study of novice task behavior examining the effect on the accessibility of an auditor's knowledge brought about by experienced-induced changes in the properties of the knowledge accessed during performance of a field task. It contributes to the goals of behavioral research in auditing by presenting basic descriptive research on how the accessibility of the knowledge driving task behavior changes with the moment-to-moment evolution of the task environment as an auditor progresses toward a solution. Research from the field of Psychology strongly supports an expectation of a relationship between an auditor's accessible knowledge and the task environment as it is transformed by that auditor's task behaviors. Although auditing behavioral research has explicitly or by implication examined specific aspects of the relationship between environment and auditor judgment, decision making, and behavior, the link has never been subjected to empirical examination in a dynamic and broadly generalized manner.

A model of the interaction among environment, accessible knowledge, and task behavior is presented, together with a methodology for quantifying the properties of that portion of an auditor's knowledge being accessed at various points during the solution process. The model is then used to analyze how the accessible knowledge of four first-year auditors is affected by environment-induced changes in their knowledge properties as they perform audit-related tasks in simulated auditing environments. The evidence suggests that these novice auditors are not a homogeneous group in terms of how their knowledge base responds to changes in the environment as they progress toward a task solution. Findings reported show considerable inter-auditor variation in the effects of environmental evolution on both the properties of these auditors' accessible knowledge and the pattern of the specific properties affected. It is proposed these variations reflect differences in knowledge base structure affecting the magnitude of the knowledge search effort, knowledge base effectiveness when called upon to supply information, and the efficiency of knowledge access. An interesting consequence of this research is that the findings disabuse us of the naive assumption that everything an auditor knows or has learned as a result of professional education and experience is always accessible for use whenever needed. Instead, this research shows that only a portion of that knowledge is actually accessible to at any moment, *viz*, that portion made accessible by the environmentally induced context within which an auditor is performing. The implications of these findings for professional practice and expertise research are discussed.

I. INTRODUCTION

Understanding the nature of expertise and how expertise is acquired is a primary goal of auditing behavioral research. Reflecting a belief that professional behavior is knowledge driven, the bulk of extant behavioral research in auditing has focused on the substantive content of the knowledge utilized while performing a task, how that knowledge is processed in arriving at judgments and making decisions, and how various aspects of the task environment affect auditor behavior (see Arnold & Sutton, 1997, and Ashton & Ashton, 1995, for comprehensive reviews). While the foregoing have made significant contributions toward understanding specific aspects of expertise, after a review of behavioral research in auditing, Bowman & Bradley (1997: 120) conclude that there continues to be a need for greater understanding of the process of expert development, an understanding that can lead to more effective auditor training, selection, assignment, and performance.

This paper is the first of a series examining the task behavior of novice auditors with the objective of contributing to an enhanced understanding of the nature of auditing expertise and how it is acquired. The specific question addressed in this paper is the relationship between task environment, the properties of the accessible knowledge, and task behavior. Although auditing behavioral research has explicitly or by implication examined specific aspects of the relationship between environment and auditor judgment, decision making, and behavior, the link has never been subjected to a dynamic and broadly generalized examination. This paper departs from the approaches found in extent behavioral research by abstracting from substantive content to focus instead on knowledge properties within a broad class of tasks possessing characteristics typical of those performed in the field by auditors during their first two or three years of professional experience. The kind of tasks to which this study generalizes, *empirically intense* tasks, are characterized by substantial information input from the task environment, application of a considerable body of domain and task knowledge, and solutions requiring substantial interaction with and transformation of the task environment (Russo 1997, 2002). In such tasks, the environment necessarily undergoes transformation as a result of the auditor's own task behaviors. The research question addressed in this paper is: In what way(s), if any, is an auditor's accessible knowledge affected by the evolution of the task environment as the auditor proceeds toward a task solution.

To answer this question, the accessibility of knowledge utilized by each of four auditor-subjects during sub-intervals of an extended period of behavior observation are compared with the average accessibility of the knowledge utilized over the entire observation period. Because of the relationship between behavior and environment in empirically intense tasks, any significant variation noted in these comparisons reflect the effect of environmental change on the auditor-subjects' knowledge. Findings are interpreted in terms of the magnitude of the effort with which the knowledge base is searched, the effectiveness of the knowledge search effort, and the efficiency of information made accessible by a successful search. Among the possible consequences that may accrue from answering the research question are a greater understanding of such phenomena as errors of omission and commission and the circumstances encouraging such events, an enhanced

understanding of knowledge base structure, and the contribution to assessments of auditor expertise that may be made by an understanding of the sensitivity of accessible knowledge to the task environment.

The remainder of this paper is organized as follows: Section II reviews research supporting the theoretical foundations of the model, which is presented in Section III. Section IV presents the research hypothesis. The experimental methodology is discussed in Section V. Findings are presented and discussed in Section VI, together with the implications of the findings for further research.

II. THEORETICAL BACKGROUND AND PREVIOUS RESEARCH

The research discussed in this paper is based on three foundations: (1) the relationship between environment, context, and accessible knowledge, (2) the connectionist model of memory structure and operation, and (3) an iterative model of auditor behavior in an empirically intense task. This section reviews the first two of these foundations. The iterative model is discussed in Section III.

Environment, Context, and Knowledge

Bandura (1978) has proposed a framework for studying human behavior in social situations based a mutual interaction among environment, the self, and behavior. This framework together with findings from the field of Psychology support an expectation of a relationship between an auditor's accessible knowledge and that auditor's task environment as it is transformed during performance of a field task. In addition, two decades of accounting and auditing behavioral research replete with studies of judgment and decision-making, cognitive processes, and related topics attest to a strongly held belief that knowledge is the driver of task behavior. Included in this body of research is the notion that the knowledge an auditor brings to bear in performance of any task is conditioned on that auditor's moment-to-moment perceptions of the context within which behavior takes place. Supporting this notion are studies of bias in auditor judgment and decision making, the influence of environmental, social, and moral circumstances on auditor behavior, and other related factors, as will be reviewed below. This line of inquiry shows an implicit understanding that *context*, defined as *an auditor's interpretation of perceived cues from the task environment*, affects task behavior. The following paragraphs discuss more specifically some of the psychological and auditing research supporting the link among environment, context, and behavior.

Encoding Specificity

Tulving (1992) reviews extensive psychological research by both himself and others suggesting that both the environment in which a task is learned and that in which the task is performed have significant effects on an individual's abilities to access information in memory. One particularly clear and often cited example of this phenomenon, called "encoding specificity," is

Godden & Baddeley's (1975) experiment in which divers studied lists of words under two different environmental conditions: on land, and underwater. They were then asked to recall the lists in both the same and opposite environments from those in which the lists were originally learned. The results show that recall was higher in the same, and lower in the opposite environment. The writer is not aware of any formal studies of this phenomenon as it relates to auditing environments (e.g., classroom vs. field, across clients, laboratory vs. field, etc.) but logical extension, personal experience, and anecdotal evidence all seem to point to its being operative in all knowledge-driven situations, including auditing.

Passive Environmental Cues

While findings supporting encoding specificity relate to the availability of deliberately learned information, other studies show that perceptions of the task environment, even though passive, affect task behavior. Hartmann (1984: 112-116) cites extensive research in the behavior observation literature supporting the significant effects of passive environmental cues on behavior. Although the effects of these cues on task behavior have not been specifically studied in auditing research, they have been important implicit factors in some studies. For example, Meixner & Welker (1988) show that prolonged tenure under the same supervisor increases the consensus of subordinates' judgments, but that this effect does not extend to prolonged tenure with the same organization. This finding tends to suggest that the environmental features which are most effective in changing behavior are those with which an auditor most frequently interacts. In Ponemon's (1991) study of peer pressure, the circumstance having most influence on subjects' under-reporting of time was their perceptions, based on casual observations of when their colleagues left the room, of the "normal" time required to complete the task. Given these findings, the possibility that in the laboratory a subject's physical surroundings may influence task behaviors and outcomes cannot be discounted.

Subconscious Beliefs

Subjects' subconscious belief that the interactive and personal consequences of judgments or decisions need not be faced can affect behavior. This belief is often based on covert perceptions of laboratory environments. Differential behaviors can be expected when subjects know that laboratory judgment/decision making research tasks terminate with arrival at the required judgment or decision choices. Thus, because decisions will not be implemented, decision maker-subjects behave as if there will be no personally felt "cost" accruing as a consequence of their decisions. Findings from several studies suggest that conscious and subconscious perceptions of the consequences of decisions, accountability, in particular, do alter auditor behavior. For example, Peecher (1996) found that perceptions of justifiees' preferences affect auditors' assessments of client non-error explanations and their search for alternative explanations. Ashton (1990) found that the presence of incentives, decision aids, and a demand for justification affect the accuracy of auditors' judgments. Kennedy (1995) found that making a demand for counter-explanation, a form of decision justification, altered auditor’s judgments. Although in the studies cited, the environmental

manipulations were salient, might the same not also be said of passive and non-salient features of an auditor's environment? For example, Ashton suggests that the introduction of decision aids into an auditor's task environment, one of the unique features identified by Libby (1989), may change task perceptions, so affected decision makers now believe that new choice strategies are expected for successful performance.[1]

Explicit/implicit Induction of Context

What knowledge is brought to bear in performing a task is that which is evoked by the task context. That different contexts can alter behavior is, I believe, a well documented proposition (see previously cited research.) Rather, the issues of relevance to the current paper are the manner in which a context is induced during an experiment (i.e., explicitly or implicitly) and the generalizability of that form of induction to auditors performing empirically intense tasks. By way of illustration, Peecher's experiment, cited previously, explicitly provided information about client integrity and the preferences for justification of the auditor-subjects' firms. Client integrity was manipulated by providing aggregated information from fifty of the firm's partners about where the client ranked in terms of integrity in the firm's client portfolio. The firm's preference for justification was manipulated by statements urging either healthy skepticism, full consideration of all the evidence, or full utilization of the client's insights into it's own business. In the previously cited studies by Meixner & Welker and Ponemon, the environmental features that contributed to the reported effects (i.e., tenure with the same supervisor and a "normal" time to complete the task) meet the requirements for implicit induction of context since no explicit attempt was made to make these particular features salient. Yet features such as an auditor's personal history, association with the task, and the activity taking place in an auditor's immediate surroundings, and this form of induction (*viz*, covert perception), readily generalize to virtually all task situations encountered in the field.

To summarize the implications of the preceding for the research reported in this paper, environment, being the ultimate source of all cues, establishes the context of behavior. Operationally, a context increases the probability that subsequent cues will preferentially evoke certain responses. Context, therefore, and by extension, environment, delimits what knowledge will be preferentially accessible during performance of a task, and thereby proscribes the range of permissible task behaviors. The same physical environment may induce different contexts in different individuals because their available knowledge differs, and different physical environments may induce different contexts in the same individual because those environments present different stimuli. The recursive relationship between environment, knowledge, context, and behavior, is diagramed in Figure 1. Stimuli from task environment (arrow 1) activate a subset of the knowledge

[1] It is a common classroom experience that students, when given a problem to solve that contains "distractor" information, feel compelled to find where in the solution that information belongs. When questioned about solution errors resulting from such attempts, student replies often reflect the assumption that, if the information is included in the problem, it, therefore, must be relevant.

base, generating a context that continuously interprets those stimuli as cues (arrow 2). The cues, in turn, alter the accessed portions of the knowledge base, updating the context (arrow 3) as well as proscribing the permissible range of task behaviors (arrows 4 and 5). Behavior alters the environment (arrow 6). And so the cycle repeats. Almost all of the knowledge processes described are unobservable, although under suitable conditions, discussed later, certain of these events can be reported as responses to observers (arrow 7).

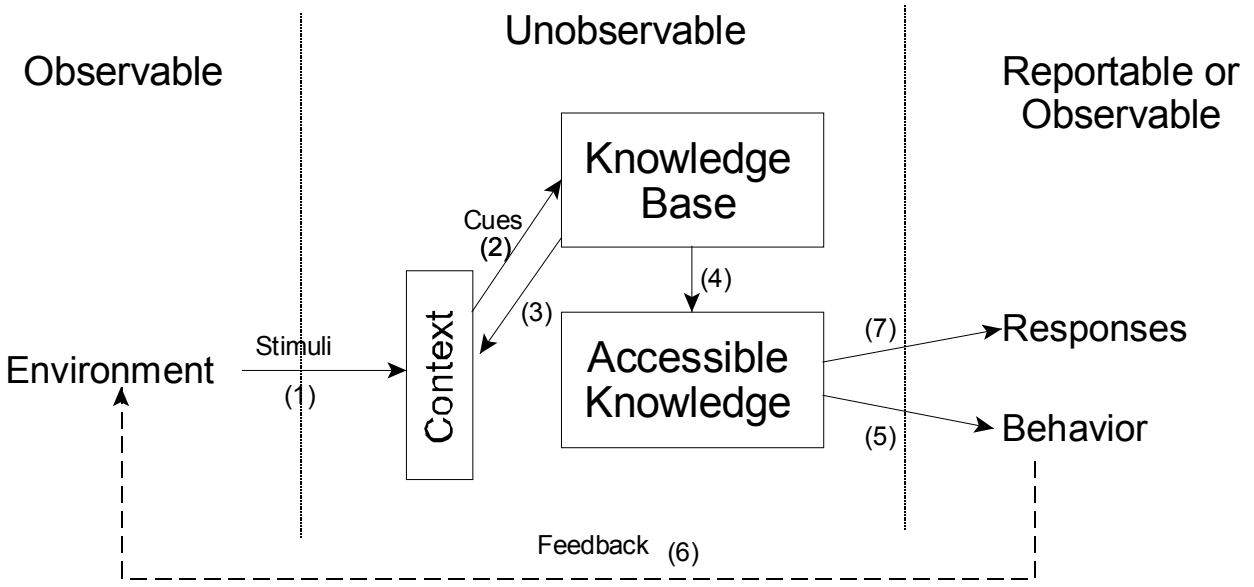

FIGURE 1
The Iterative Model of Behavior While Performing An Empirically Intense Task Showing the Interaction Between Environment, Context, Knowledge, and Behavior

Connectionist Model of Memory

In this research, a connectionist view of memory organization and function is assumed (see Rumelhart, 1989, for a review). In this view, the content of a knowledge base is distributed throughout memory in the form of micro-features of information (nodes), which are linked together to form networks of varying complexity. Knowledge base content, therefore, is represented in the patterns of linked nodes that are activated at the moment any node is accessed. Knowledge content may be thought of as directly linked in memory if it can be accessed automatically, *i.e.*, by subconscious neurological processes. Unlinked knowledge cannot be accessed directly, and is, therefore, unavailable. Cognition, along with speech, writing, and other forms of behavior, is one means by which knowledge that is not directly (neurologically) linked in memory is accessed.(Dennett, 1991; Ellis & Siegler, 1994: 434-4) The terms “virtually linked” and “virtually

accessed" may be used to represent these forms of indirect knowledge access.[2] Functionality, each virtual link potentially evokes a new context or modifies an existing context, either of which, in turn, alters the permissible range and selectivity of subsequent knowledge responses.

From a connectionist perspective, knowledge organization is defined as the extent to which information is linked in memory. At a structural rather than logical level, connectionist models of memory organization account for strength of association in terms of the number of links among knowledge elements (micro-features) and their natures (direct vs. indirect, neurological vs. virtual, etc.) Manifestation of the strength of linkages among the micro-features producing and giving expression to knowledge is an observer's perceptions arising out of the combination of (1) the consistency (*i.e.*, predictability) of the association between a given set of cues and the observed response, and (2) the availability of the knowledge expressed. The more consistent the stimulus/response association and the faster the observed response, the "stronger" the perceived association and, by extension, the linkages among the response-determining micro-features. Each episode of cognition[3] signals the use of one or more virtual links to connect otherwise neurologically unlinked elements of information in memory. Consequently, increasing the number of neurological links among knowledge micro-features results in a decrease in the complexity of the cognitive episodes and an increased perception of "strength" in the associations between cues and responses,

[2] Reber (1985) describes the term "cognition" as a broad, almost unspecifiable term referring to thinking, reasoning, and a long list of other "mental behaviors." Most pragmatically for current purposes, cognition can be thought of as vicarious activation of those areas of the brain through which sensory input, most particularly audio input, is expressed. For example, the experience of thinking during problem solving is often described as "private speech" and is hypothesized to originate out of self-directed speech engaged in by children at around age 4 or 5 (Ellis& Siegler 1994, 343-4). Even during adult problem solving, it is an almost universal experience that one will often overtly address imperatives and other verbalizations at the self, particularly at moments of stress or surprise ("Wait a minute!" or "This can't be right!"). Dennett (1991) also cites research supporting the "private speech" hypothesis and argues that cognition, along with speech, writing, and other forms of behavior, is one means that has evolved for indirectly accessing knowledge that is not directly (neurologically) linked in memory. Finally, Russo (1997) reviews research supporting a point of view consistent with both the foregoing and the automaticity literature in that cognition is the exception rather than the rule for mental activity governing behavior while performing a task. In this conceptualization, cognition is brought to bear only when there is a failure of memory to automatically supply required knowledge.

[3] The term "cognitive episode" and its variants represent a sequence of one or more reportable mental behaviors mediating observed behaviors. The term is discussed more fully in Section III.

both contributing to an increased perception of knowledge organization. The highest degree of organization is evidenced by the absence of any need for virtual links.[4]

III. MODEL

Knowledge Base Structure

Given a set of cues related to a specific domain of performance, the term "knowledge base" is used to represent all the information accessible from memory to an individual performing in that domain. Research showing that context produces selectivity in accessible knowledge suggests that information in the knowledge base is organized as numerous *clusters*, each consisting of a specialized collection of very strongly linked nodes.[5] With very specialized clusters,[6] the sensitivity

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[4] The "strength" of an association between cues and expressions of the knowledge they elicit is a perception one forms based upon the "difficulty" experienced in effecting the knowledge evocation. Difficulty is normally thought of in terms of time or cognitive effort (e.g., O'Donnell 1996). Tulving (1992) discusses this matter in detail and cites extensive relevant research by both himself and others. In summary, Tulving accounts for the perceived strength of the association between cues and elicited knowledge by a combination of (1) the semantic vs. episodic content of knowledge, (2) the closeness of the match between cues encoded at the time the knowledge was acquired and cues presented at the time of retrieval, (3) the extent to which the demand for knowledge can be satisfied by recognition or recall, and (4) the knowledge search strategies employed by the rememberer. All of these factors, but particularly the second and third, are largely a function of the context in which knowledge retrieval is required.

[5] The term "cluster" is used in preference to the more general term "network" to denote a strongly linked subset of nodes or related micro-features. If one were to visualize the network that is the knowledge base as a very large web in which there are a greater or lesser number of "holes," areas of the web that lack a significant number of connecting threads or none at all, then clusters would be analogous to the disbursed "islands" of locally complete web-work separated by the "holes." Structurally, therefore, the network is hierarchical, with micro-features (nodes) at the bottom, clusters of micro-features at intermediate levels, and the knowledge base at the top.

[6] The term "specialized" is used to connote information that makes finer distinctions among contexts than otherwise would be the case when cues are perceived. For example, an experienced auditor will be able to discriminate many more contexts in which the term "Accounts receivable" is a cue than, say, a first-year accounting student. To the accounting student, the most probable context in which the term may occur is an examination question or assignment. For the auditor, perception of the term may induce such contexts as the accounting for and presentation of these assets on a balance sheet, the client's procedures for estimating the provision for losses in collection, controls over billing and collection, procedures for confirmation, the going concern risk arising from the client's dependence upon one very large

of the information content made accessible by changes in cue stimuli is likely to be greater than would be the case if clusters were less specialized or of relatively low information content.

Clusters vary in their specialization and the ways in which they are linked.[7] Among themselves, inter-cluster links can range from weak to none at all. It is the extent of cluster specialization and the relative presence or absence of inter-cluster links that account for the effect of context on knowledge properties and task behavior. The perception of context is primarily a sub-conscious process and, therefore, involves strongly linked information clusters. Greater specialization of information clusters increases the discriminatory power of the knowledge base; the information content of clusters and their manner of linkage affect knowledge properties; both affect task behavior.

The Iterative Model

Russo (1997, 2002) describes the process by which auditors perform empirically intense tasks by an *iterative model of task behavior*. Task behavior proceeds as a sequence of observable *target behaviors* (reading, inquiry, calculating, writing, etc.) mediated by episodes of subconscious (automatic) and conscious (cognitive) mental activity. During performance of such tasks, behavior proceeds according to an *iterative process* in which information is acquired from the task environment, processed in memory, and the environment transformed in accordance with the outcome of that processing. In thus transforming the task environment, environmental stimuli upon which the selection of behaviors in succeeding iterations is based are altered. Figure 1, previously described, presents a representation of the iterative model highlighting the interaction between environment and accessible knowledge. Three broad categories of events are depicted: observable events (those visible to a trained observer of task behavior), unobservable events (mental activity occurring within the auditor's brain), and reported events (the concurrent verbalizations of cognitive

customer, financing by pledging the receivables, and many others, most of which would never occur to the student. Which of these possibilities obtains at any time depends on other cues that may be associated with the "accounts receivable" cue.

[7] The mechanism by which clusters are created is beyond the scope of this paper. The most likely mechanism is that suggested by research on encoding specificity. However, that such clusters exist is amply supported by the Psychological research.

mental activity while performing a task.).[8] The frequency and character of unobservable events are inferred from analysis of the auditor's observable behaviors and reported cognition.[9]

As discussed earlier, the operational effect of a context is to cause certain subsets of the knowledge base to become more accessible than others, thereby increasing the probability that certain behaviors will be preferentially evoked. By implication, therefore, an auditor's knowledge base may have extensive information content, but that content cannot be accessed except as permitted by the filtering effect of the context active at the moment. By analyzing the patterns of observed behaviors and reported knowledge base responses, the properties of the knowledge being accessed and driving the observed behaviors may be inferred.

Knowledge Base Responses and Knowledge Properties

Each instance of a behavior performed serves as a probe of an auditor's knowledge base. These probes produce the samples of responses that, in turn, are the basis for making inferences about the properties of the knowledge driving those behaviors. Data for measuring the level of each of the knowledge properties over a set of target behaviors[10] are derived from an analysis of the knowledge base responses that form the episodes of mental activity mediating transitions to each behavior. Three forms of response are identified: subconscious transitions to target behaviors, cognitive responses indicating a positive outcome from a search of the knowledge base, and cognitive responses indicating that sought knowledge is either not accessible or not present in the knowledge base. The first of these responses is referred to as being *automatic*. The two kinds of cognitive response mentioned are referred to as, respectively, *analysis and planning* cognition and *uncertainty* cognition, terms that are roughly descriptive of their tenor and content. The sum of automatic and analysis and planning responses is a measure of *accessible knowledge content*. The number of responses making up a cognitive episode is that episode's *complexity*, and is negatively related to the extent to which information is organized in the knowledge base.

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[8] The adjective "reportable" refers to the potential to make salient to an observer other than the "thinker" (i.e., to the external environment) an otherwise ongoing but hidden phenomenon. Conscious mental activity (e.g., "thinking") is normally hidden from the external environment unless the "thinker" communicates or reports his/her experience of that activity. Extensive research (see Ericsson & Simon 1993 for an review) shows that concurrent verbal reports of thoughts at the "focus of attention" are valid expressions of the underlying cognition.

[9] Details of behavior observation and concurrent verbalization of cognitive activity are discussed in Section V.

[10] Target behaviors are the specific behaviors recognized by the behavior observation coding system. In this paper, any reference to observed behavior is implicitly a reference to one or more target behaviors. The target behavior coded in this research are (reading, inquiry, calculating, writing, and other (e.g., organizing, indexing, searching, etc.))

Russo (1997, 2002) defines and examines three properties of a knowledge base: organization, content, and availability, and shows how levels of these properties, measured by a set of serially dependent properties ratios, are directly related the accessibility of knowledge.

> *Knowledge organization* describes the amount of cognitive searching of a knowledge base required before an observable behavior is evoked. Knowledge organization is negatively related to the complexity (*S*) of mediating episodes.
>
> *Accessible knowledge content* refers to the capacity of a knowledge base to respond positively to a demand for information required to evoke a given target behavior. Automatic responses and analysis and planning cognition are indications of positive knowledge base responses. Given the complexity of mediating episodes, accessible knowledge content (C) is measured by the proportion of knowledge base responses that are positive.
>
> *Knowledge availability* refers to the capacity of a knowledge base to automatically supply on demand the information required to evoke a given target behavior. Given that a knowledge base responds positively, knowledge availability (*V*) is indicated by the proportion of positive responses that are automatic.

Implementation

The effect of environmental evolution on knowledge accessibility is mediated by its moment to moment effects on the properties of that portion of the knowledge base that is made accessible by the context. In general terms, the model measures the properties of the knowledge accessed in each of several sub-intervals of an extended period of behavior observation and compares these with the average properties of the knowledge utilized over the entire observation period. Because performance of an empirically intense task necessarily changes the task environment, any significant variation between the resulting metrics ("properties effects") during any sub-interval and those over the full period of behavior observation is a consequence of the effect of the evolving the task environment on that auditor's accessible knowledge. The properties effects also provide insight into the structure of an auditor's knowledge base. The methodology for producing these measures is discussed next.

The complete protocol of a subject's behaviors and mental responses (the "solution sequence") is sectioned into *T* intervals of equal duration.[11] Each interval, *t*, has associated with it

[11] Equal intervals are not a requirement. Within certain limits, intervals may be of unequal duration, as may suit any particular research objective. Decreasing data density with shorter intervals reduces the power of statistical tests and thereby places a practical lower limit on interval size. On the other hand, larger intervals submerges possible knowledge properties effects into a larger aggregate, thereby making the identification of temporal patterns in the effects, a primary objective of this research, less likely to be revealed.

a set of behaviors, $\{j\}_t$, the count, b_t, of the number of elements in this set, and for each such element (a particular type of target behavior), its frequency of occurrence, n_{jt}, and the kind ($k \in \{s, c, v\}$) and frequency (n_{kjt}) of the mental responses of the related mediating episodes. Adapting Russo's model, the properties of knowledge mediating transition to each target behavior in each interval are measured as shown in equation 1,

$$S_{jt} = \frac{n_{sjt}}{n_{jt}}, C_{jt} = \frac{n_{cjt}}{n_{sjt}}, V_{jt} = \frac{n_{vjt}}{n_{cjt}} \quad \textbf{(1)}$$

where n_{vjt} is the frequency of automatic knowledge responses, n_{cjt} the frequency of automatic and positive cognitive responses, and n_{sjt} is the frequency of all responses (automatic, positive cognitive, and negative cognitive responses). For the solution sequence as a whole, the knowledge properties are found from equation 2.

$$S_j = \frac{n_{sj}}{n_j}, \quad C_j = \frac{n_{cj}}{n_{sj}}, V_j = \frac{n_{vj}}{n_{cj}} \quad \textbf{(2)}$$

The product of the three knowledge properties determines the knowledge accessibility, defined as the average automaticity of the set of behaviors, $\{j\}$, performed during any period of behavior observation (*i.e.*, $c^{\{j\}_t} = \frac{1}{b_t}\sum^{\{j\}_t} S_j C_j V_j$). In this paper, we are most interested in the contribution to knowledge accessibility in each interval made by the effect of environmental evolution on each knowledge property compared with the properties of knowledge accessed over the solution sequence. In measuring each of these effects, the serial relationship of the properties must be taken into account. Accordingly, let us define the *complexity mix* as the ratio of the episode complexity of each behavior in an interval to the total complexity of all behaviors in the same interval, *i.e.*, $m_{sjt} = S_{jt} \Big/ \sum^{\{j\}_t} S_{jt}$. For the solution sequence, the same relationship applies except for omission of the *t* subscript. Let us also define the *responsiveness ratio* as the ratio of average positive responses per instance of a target behavior in an interval to the sum of all such averages for that interval's behavior set, *i.e.*, $m_{cjt} = S_{jt}C_{jt} \Big/ \sum^{\{j\}_t} S_{jt}C_{jt}$. Again, for the solution sequence, the same relationship applies except for omission of the *t* subscript. With these relationships, the properties effects are computed from equation 3.

$$A_{st} = \frac{\sum^{\{j\}_t} S_{jt}}{\sum^{\{j\}_t} S_t}, \quad A_{ct} = \frac{\sum^{\{j\}_t} C_{jt} m_{sjt}}{\sum^{\{j\}_t} C_j m_{sj}}, \quad A_{vt} = \frac{\sum^{\{j\}_t} V_{jt} m_{cjt}}{\sum^{\{j\}_t} V_j m_{cj}} \quad (3)$$

The relationship of knowledge accessibility in each interval to average knowledge accessibility is the product of the three knowledge properties effects, *v*iz, $A_t = A_{st}\, A_{ct}\, A_{vt}$.[12]

[12] The knowledge properties are defined in such a way that their product is automaticity of each behavior (*i.e.*, for each target behavior, the ratio of automatic knowledge base responses to the behavior frequency, see equations 1 and 2). Knowledge accessibility is defined as the

Interpretation of Knowledge Properties Effects

Each knowledge property effect reflects, relative to what is the case over the solution sequence, the way some aspect of the knowledge accessed during each interval is affected by the auditor's environmental perceptions. Because they are serially related, the interpretation of any knowledge property effect will be dependent on the measures of one or more of the other effects. These interpretive matters are discussed next.

A_{st} is positively related to the number of virtual links traversed in searching the knowledge base during any interval compared with the number traversed over the solution sequence, being a reflection of the relative complexity of the episodes of mental activity mediating evocation of an interval's set of target behaviors. As such, it is a positively related *measure of the relative magnitude of the search effort*. It is not possible to measure the total number of information clusters making up a knowledge base because, while each response represents one link to a node in an information cluster, there may be many nodes in the cluster, each capable of being linked to other clusters. Thus, the complexity effect can only indicate the relative number of *links* traversed (not clusters present) during an interval versus the average number traversed over the solution sequence.[13]

A_{ct} is a measure of the extent to which the accessed portion of a knowledge base can discriminate among alternative contexts compared with the same ability over the solution sequence. Not all information retrieval attempts will result in a positive outcome. Even if the knowledge base has a substantial discriminatory ability, it may not have any information that is positively related to the particular environmental cues being perceived at the moment. The resulting inability to integrate

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average automaticity of behaviors occurring in any period of behavior observation. The product of the knowledge properties measures (knowledge properties effects) determine the knowledge accessibility (knowledge accessibility effect) for any interval or for the solution sequence as a whole (omit the *t* subscript) as shown by the following equations:

$$c_t = \tfrac{1}{b_t}\sum^{\{j\}_t} n_{vjt} / n_{jt} = \tfrac{1}{b_t}\sum^{\{j\}_t} S_{jt}C_{jt}V_{jt},\ A = c_t / c$$

Individual knowledge properties and knowledge properties effects are measured rather than knowledge accessibility for two reasons. First, because knowledge properties (knowledge properties effects) can offset one another, measurement of individual properties effects is a more sensitive testing strategy than attempts to measure and test knowledge accessibility directly. Second, measures of individual properties and their effects are diagnostic as to the manner in which environment affects knowledge accessibility, information which would be lost if knowledge accessibility and its effects were measured directly.

[13] Another implication of this relationship is that, because a cluster can be made up of more than one node, it is possible for there to be multiple links to the same cluster if there are links to different nodes in the same cluster.

all evoked information into a consistent context generates substantial uncertainty and confusion, which, in turn, decreases both the relative efficiency of the search effort and the measure of accessible knowledge content. Therefore, A_{ct} must be interpreted along with the A_{st} effect as *an indicator of the relative effectiveness of knowledge base search effort*.

A_{vt} is a measure of the relative knowledge content of the accessed clusters compared with that of the clusters accessed on average over the solution sequence. This indicator must be interpreted in conjunction with the relative effectiveness of knowledge search. Given a positive outcome of a knowledge base search, A_{vt} is a measure of the *relative amount of information that is made available in a single access* of the knowledge base. If the information content of the clusters is sufficient so that all the information needed to act automatically in the context is available, then A_{vt} will be higher than the average over the solution sequence.

IV. HYPOTHESIS

The objective of the empirical aspect of this paper is to detect the temporal pattern, if any, in the knowledge properties of auditors during performance of a field task. The null hypothesis is:

> In any observation interval, given the set of behaviors performed, the properties of the knowledge base utilized in that interval are the same those of the same behavior set over the entire solution sequence.

As stated in the null hypothesis, the information about behaviors performed in each interval is taken as given, Therefore, it is assumed that in each interval the coding of observed behaviors as to type and frequency is made without error. However, the complexity and composition of the episodes of mental activity mediating behaviors during any interval are observed with non-systematic (*i.e.* random) error. Therefore, observed deviations in the properties of knowledge used in any interval from expectations based on properties measured over the solution sequence may be due to either experimental error or to real differences. It is the latter, of course, that are the metrics of interest. To take the effects of experimental error into consideration, the null hypothesis is broken down into three operational hypotheses that test for the significance of the properties metrics in each interval. These operational hypotheses, their expectation based on the null, and the indications of possible outcomes are summarized in Table 1.

TABLE 1
SUMMARY OF OPERATIONAL HYPOTHESES

Operational hypothesis	Indications
$H_0 1$: $A_{st} = 1$	The effect of environment on knowledge organization. Values > 1 indicate less organized knowledge than average, a possible less than average accessible knowledge content, or a relatively high proportion of unavailable content; values <1 indicate a more organized than average knowledge content, a higher than average level of accessible knowledge content, or a higher than average proportion of available information content.
$H_0 2$: $A_{ct} = 1$	Effect of environment on knowledge content. Values > 1 indicate a greater than average proportion of positive information retrieval outcomes (*i.e.*, higher than average accessible knowledge content); values < 1 indicate that a greater than average proportion of information retrieval attempts produced negative results (*i.e.*, less than average information content).
$H_0 3$: $A_{vt} = 1$	Effect of environment on available knowledge. Values >1 indicate a greater than average proportion of knowledge content that is accessible automatically; values < 1 indicate that a greater than average proportion of knowledge content is accessible only with cognitive effort.

With respect to these operational hypotheses, if the null is true, then the knowledge properties observed in any interval will be the same as those observed for an identical set of behaviors over the entire solution sequence (referred to in Table 1 as the "average" properties). Because the knowledge properties effects are expressed as ratios of interval effects to solution sequence effects (see equation 3), the expectation for each effect under the null is a ratio of 1. Rejection of any of these hypotheses implies that the distribution of knowledge base responses in that interval is so different from the distribution of knowledge base responses for the same behavior set over the solution sequence as not to be attributable to non-systematic error at the accepted level of type I risk. Any rejection of an operational null in any interval is evidence of the effect of the environment on the accessibility of that portion of the auditor's knowledge base being accessed during that interval. Both increases and decreases in each knowledge property are relevant to the objectives of this research. Hence, a two-tail test is used.

V. EXPERIMENTAL METHODOLOGY

The details of the experiment performed and behavior observation methodology employed to obtain data on auditor behavior during empirically intense tasks are too lengthy and complex to be covered here. The following paragraphs present only a brief summary. For a more complete discussion, see Russo (1994, 1995).

Subjects, Task, and Procedure

Both inexperienced auditors and a non-financial-audit related task were chosen for this experiment in order to assure that the subjects would confront a task situation challenging familiar contexts. The Subjects were four first-year auditors from the professional staff of a Top Tier (formerly Big Six) auditing firm. All Subjects were volunteers who had sat for and passed some, but not all, parts of the CPA examination and all had no prior exposure to the subject matter of the task.

The task in this experiment was a review of the Statement of Operating Expenses of a new office building in which the client is a tenant, rendered pursuant to the rent escalation provisions of the client's lease. To acquaint them with the terminology, administrative, and computational procedures associated with operating expense rent escalations, on the day before the experiment, each Subject was given background material and two samples of completed review reports to study. However, none of this material provided any information on examination or reporting procedures, the landlord's procedures, or the existence and nature of any documents used in the preparation of the statement rendered to the client. Therefore, such a task, to the extent that it differs from that of financial audit, would be unfamiliar to the Subjects who participated in this experiment.

Each Subject performed the task on a different day. The task was performed in a simulated business office in which each Subject was presented with the equipment and supplies normally available in audit environments and the ability to communicate (via intercom) with and receive documents (via a mail slot) from other parties present in the task environment (e.g., client personnel, the audit partner, etc.). During performance of the task, each Subject was free to contact any party in the task environment and to request any documents or explanations required. Although the researcher played the roles of others in the task environment, no face-to-face or verbal contact took place between Subject and experimenter. Responses to requests for explanations were communicated to the Subject via a video display at the Subject's desk.

Behavior Observation Methodology

Synchronized video-taped and think-aloud verbal protocols were used to capture both the observable behaviors and cognition of the Subjects during their performance of the task. The experimental protocols were independently coded in terms of the behaviors and cognition described in Appendix A by the researcher and a first year doctoral student trained by the researcher. Kappa

(Cohen, 1960), a widely used measure of the agreement between independent coders, ranged from .78 to .72 over a total of approximately 8 hours of behavior observation. These levels of Kappa are significant at $p < .0000$.

Tests Of Hypotheses

There are two aspects of an auditor's knowledge that are examined in this paper. The first is the identification of intervals in which the properties of the knowledge accessed differed significantly from average, and the second is the pattern of intervals having significant properties effects in each subject's solution sequence.

Intervals of Significantly Different Knowledge Properties

The phenomena being examined in this research are by nature discrete and data densities in each observation interval are generally very low (frequencies typically in the range of 10 to approximately 25 instances). In addition, the relationships among the various kinds of data are complex. For these reasons, probability densities required for testing the operational hypotheses must be generated by means of Monte Carlo simulation. Further, because each interval is likely to present a unique set of behavior and frequency data, each requires generation of its own unique density distribution. In this experiment, 120 different probability distributions are necessary (3 properties, 4 subjects, 10 observation intervals each.) In view of the preceding, rather than reporting outcomes with the levels of significance indicated as in normally done in experimental research, in this paper, observed outcomes and the two-tail probability of each as generated by the Monte Carlo simulations are reported.[14]

The Monte Carlo simulations are based on three inputs from each subject's solution sequence: (1) the distribution of the complexity of mediating episodes, (2) the distribution of response types at each level of episode complexity, and (3) the frequency of each behavior in each interval of the solution sequence. Each combination of interval and property for each subject was simulated 10,000 times to arrive at the probability densities for testing the properties ratios. In the interests of brevity, further details of the simulation procedure have been placed in the endnotes.[15]

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[14] At the low end of statistically significant outcomes, the cumulative probability ($\alpha/2$) of the observed outcome or less is reported. At the upper range, the probability of the observed value or greater ($1- \alpha/2$) is reported.

[15] Input into the simulation consists of (1) the distribution of complexity of mediating episodes for the solution sequence, target behavior by complexity level, (2) the distribution of knowledge base responses over the solution sequence, given a level of complexity, behavior by response, (3) the interval to be simulated, and (4) the number of iterations of the simulation. Five target behaviors and ten levels of complexity were used. Each combination of knowledge property and interval was simulated 10,000 times. The simulation performed for a specific

The volume of data precludes inclusion of the density distributions in this paper. The full set of data will be made available to interested researchers on request.

Pattern of Significant Properties Effects

The term "pattern" is used in the restricted sense of the number of intervals in which are found significant properties effects. This test can only be performed after having determined the number of such intervals. The probability of rejecting any of the operational nulls in any interval is set at α. The null tested for each subject's pattern is that the number of significant intervals found is due to non-systematic error, with $p = \alpha$. In each case, there are thirty tests made for each subject (3 properties, 10 intervals each). The probability of observing x or more significant outcomes in 30 tests is then described by the cumulative binomial distribution.[16]

VI. FINDINGS

Table 2 presents for each subject and interval the observed measure of each knowledge property and the probability, based on Monet Carlo simulation, of obtaining the observed measure or less under the null hypothesis. Significant properties findings are indicated by an asterisk. Indications of statistical significance include any property effect for which the probability of observing the value of each metric obtained or less is .025 or less at the lower tail, and .025 or more at the upper tail (two tail test, α=.05) Significant patterns of properties findings are indicated by tick marks at the top of the indicator column for each subject.

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interval proceeds as follows:

```
For each iteration of the simulation
    For each behavior in the behavior set
        For each instance of that behavior
            Select a mediating episode complexity
            For each element of the mediating episode
                Select a knowledge base response, given the complexity
level
                Accumulate the response vector for the episode
            Next element
        Next instance
    Next behavior
    Compute properties metrics
    Update the density distribution
Next iteration
```

[16] The probability of x or more successes in n trials is given by $\sum_x^n \binom{n}{x} p^x (1-p)^{(n-x)}$

The table shows eight intervals in which the properties of Subject 1's accessible knowledge was significantly different than average for the solution sequence. This *pattern* of findings is statistically significant at p=.001. Subject 4 also shows a very significant pattern, but of six rather than eight intervals (p=.003). The number of significantly different intervals for Subjects 2 and 3 do not indicate a significant pattern of knowledge properties effects.

Both of the subjects for which there are significant patterns of environmental effect (Subjects 1 and 4) show significant differences in all three knowledge properties. Subject 3 shows significant effects only in the complexity and availability properties. In the intervals where there are significant properties metrics, the complexity of the cognitive effects of Subjects 1 and 3 increased while that of Subject 4 decreased. Finally, while the environmental effects of Subjects 1 and 4 are more or less spread out over the period of the solution sequence, those of Subjects 2 and 3 are concentrated into the early intervals.

Discussion and Conclusions

The research question posed in the Introduction is: In what way(s), if any, is an auditor's accessible knowledge affected by the evolution of the task environment as the auditor proceeds toward a task solution? The findings show clearly that the four auditors who participated in this experiment are not a homogeneous group with respect to the sensitivity of their knowledge bases to changes in their task environments. There are significant inter-auditor variations. Subjects 1 and 4, on the one hand, show eight and six significant properties effects, respectively, while Subjects 2 and 3, on the other hand, show only one and three, respectively. There are also noticeable variations in specific properties affected. Subject 1, for example, shows a greater number of significant knowledge organization (A_{st}) and knowledge availability (A_{vt}) effects than Subject 4, while the type of response sensitivity of Subject 2 is completely different from that of Subject 3.

TABLE 2
SUMMARYOF FINDINGS

	Subject 1			Subject 2			Subject 3			Subject 4		
t	*Ast*	prob(see notes)	#	*Ast*	prob(see notes)		*Ast*	prob(see notes)		*Ast*	prob(see notes)	#
1	0.885	0.401		0.927	0.493		1.374	0.145		0.564	0.138	
2	0.767	0.172		0.928	0.450		1.545	0.050		2.126	0.030	
3	**1.604**	**0.018**	*	1.019	0.383		**1.711**	**0.003**	*	1.455	0.082	
4	0.918	0.447		0.932	0.506		0.927	0.273		1.254	0.121	
5	0.905	0.402		1.104	0.158		1.266	0.049		0.887	0.396	
6	1.387	0.065		0.931	0.386		1.402	0.068		1.314	0.139	
7	0.870	0.402		1.187	0.086		0.934	0.317		**0.717**	**0.008**	*
8	0.994	0.332		0.764	0.071		0.897	0.349		0.772	0.122	
9	0.959	0.431		0.796	0.193		0.982	0.510		0.895	0.396	
10	**1.527**	**0.012**	*	0.941	0.588		0.805	0.045		1.020	0.358	
t	*Act*	prob(see notes)	#	*Act*	prob(see notes)		*Act*	prob(see notes)		*Act*	prob(see notes)	#
1	**1.437**	**0.018**	*	1.022	0.474		0.875	0.261		**1.347**	**0.000**	*
2	1.080	0.462		0.861	0.191		0.796	0.195		0.937	0.280	
3	0.844	0.191		0.891	0.183		0.921	0.306		0.915	0.258	
4	1.295	0.069		**1.209**	**0.011**	*	0.997	0.481		0.944	0.274	
5	1.075	0.328		0.998	0.456		0.892	0.225		**0.735**	**0.025**	*
6	0.696	0.086		0.984	0.408		1.173	0.223		0.820	0.197	
7	0.731	0.136		1.030	0.475		0.994	0.481		1.113	0.100	
8	0.783	0.187		1.201	0.145		0.940	0.319		1.123	0.090	
9	**1.269**	**0.025**	*	1.212	0.133		1.095	0.200		1.021	0.465	
10	0.864	0.242		0.743	0.124		0.912	0.228		1.029	0.456	
t	*Avt*	prob(see notes)	#	*Avt*	prob(see notes)		*Avt*	prob(see notes)		*Avt*	prob(see notes)	#
1	1.152	0.402		1.079	0.425		1.127	0.464		0.564	0.269	
2	**1.863**	**0.018**	*	1.720	0.120		**0.336**	**0.023**	*	0.448	0.270	
3	**0.260**	**0.025**	*	0.835	0.347		**0.084**	**0.002**	*	0.351	0.061	
4	0.870	0.369		1.013	0.483		1.165	0.276		1.024	0.460	
5	1.254	0.298		0.973	0.450		0.854	0.337		**0.000**	**0.004**	*
6	0.636	0.210		1.289	0.166		0.971	0.474		0.101	0.094	
7	**0.000**	**0.001**	*	0.619	0.084		0.791	0.228		**1.903**	**0.003**	*
8	0.748	0.257		1.508	0.112		1.494	0.181		**2.238**	**0.006**	*
9	1.256	0.223		1.231	0.317		1.365	0.097		0.000	0.117	
10	**0.000**	**0.019**	*	1.297	0.258		1.080	0.430		0.925	0.431	

Notes: This table shows, for each subject and property metric, the observed value of the property effect (*Ast*, *Act*, and *Avt*) and the probability in any interval (by Monte Carlo simulation) under the null hypothesis of obtaining the observed value or less for the lower tail and the observed value or more in the upper tail . Significant 2-tail findings (p=.05) are indicated by an asterisk. The probabilities of observing the number of significant intervals or greater in 30 intervals per subject are .001, .785, .188, and .003 for Subjects 1 to 4 respectively (see text). # Significant pattern, p<=.05

In interpreting these wide variations in findings the discussion of knowledge base structure in Section III is very relevant. Each significant property ratio represents an instance in which the auditor encountered a context requiring a substantial change in accessible knowledge. For Subjects 1 and 4, the properties of the altered subset of information clusters being accessed were sufficiently different from the average of those accessed over the solution sequence so as to produce the properties effects observed. The same cannot be said for Subject 2 and, to a lesser extent, Subject 3. Clearly, then, the knowledge bases of Subjects 1 and 4 are structured differently from those of Subjects 2 and 3.

The pattern of specific properties affected suggests differences among the auditors in the quality of various aspects of their knowledge base structures. Quality assessments, in general, reflect differences in structure that affect the effort expended in knowledge search, knowledge base effectiveness when called upon to supply information, and the quantity of information made available with each access as they occur in any interval compared with their occurrence over the solution sequence. The differing patterns of properties effects reported reflect intervals over the course of performing the task when these auditors encountered environments that were more or less familiar to them, or for which their knowledge base was more or less able to supply adequate information, or that the information, if present in the knowledge base, was readily accessible. These structural differences have implications for enhancing our understanding of the process by which expertise develops.

The Process of Expert Development

It is widely recognized that automaticity in performance of a task is a sign of expertise (Alba and Hutchinson, 1987; Anderson 1982, 1987; Mayer 1992: 305; Davis & Solomon; 1989; Bedard, 1989). Highly automatic task behavior exhibited over the duration of a task implies a knowledge structure consisting of very large information clusters. An auditor having such a structure would show a virtually null outcome in an experiment like the one reported in this paper, necessitating the level of that auditor's expertise to be discerned from other information, including of patterns of observed task behaviors. As an auditor progresses toward a high level of task automaticity, it appears that a two step process is required. First, the greater discriminatory capabilities of expert auditors requires development of clusters of progressively greater specialization. Second, with further experience, these clusters, initially unlinked, gradually become linked, increasing the availability of their information content.[17] Consequently, the relatively high numbers of significant properties effects for Subjects 1 and 4 are indicative of auditors in the early stages of developing expertise. However, findings regarding Subjects 3 and, especially, Subject 2 do not render clear signals. Given the similarity of all four Subjects in educational and professional background, it is unreasonable to attribute the relatively low number of significant properties effects found for Subjects 2 and 3 to random behavior, a lack of any change in the task environment as a result of their task behaviors, or a high level of expertise. Whether these two subjects are much further along in the expert development process than are Subjects 1 and 4 or if, in the alternative, they are in the very early novice stages is matter for further analysis.[18]

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[17] For purposes of exposition, a two stage process is described. In fact, the increase in both cluster specialization and knowledge availability proceed in tandem. The process involves both strengthening of links among some micro-features (increasing availability) and the weakening of links to others (increasing specialization). The primary engine driving this process is the continuing exposure to learning opportunities with filed experience.

[18] Random evocation of task behaviors would produce a uniform pattern of knowledge properties throughout the solution sequence. In the very early stages, novice auditors lack a

Opportunities for Further Research

What kinds of environmental events might cause such a substantial change in the demands made on an auditor's knowledge base as to produce the properties effects described in the findings? Although not empirically investigated in this paper, the findings reported here suggest investigation of an auditor's perception of sub-tasks as one source, perhaps the major source, of the effect of environmental evolution an auditor's knowledge properties. Perceptions of new sub-tasks making significantly different demands on an auditor's knowledge base may arise in four ways. First, they may arise as a consequence of the auditor's own inappropriate behaviors, lack of appropriate knowledge, discovery and correction of one's own errors of omission or commission, and other indica of inexpert or unskilled behavior. Second, unexpected findings during execution of audit procedures may trigger perception a new sub-task. Third, sub-tasks can arise out of encounters with new task situations that force an auditor to seek parallels from prior education or experience, adapt familiar solutions to new demands, seek additional information from the environment, or otherwise deal with a knowledge retrieval failure. Finally, new sub-tasks flow from the normal structure of field tasks, in which completion of one procedure is followed by the commencement of the next. Anecdotal considerations and personal experience would suggest that all realistic field tasks are at some level resolvable into a hierarchy of related sub-tasks (*e.g.*, consider the typical audit program).

The significantly different demands an evolving environment can make on an auditor's knowledge base act as obstacles to consistent knowledge accessibility. Based on the foregoing, to use an analogy of a river flowing to the sea, the findings suggest that Subjects 1 and 4 may have perceived their task experiences as a more undulating meander around a landscape of barriers to a greater extent than did Subject 3 and, especially, Subject 2.

Conclusion

An interesting consequence of this research is that the findings disabuse us of the naive assumption that everything an auditor knows or has learned as a result of professional education and experience is always accessible for use whenever needed. Instead, this research shows that only a portion of that knowledge is actually accessible to at any moment, *viz*, that portion made accessible by the environmentally induced context within which an auditor is performing. During performance of a task, unless the context permits an auditor to form virtual links to other information, the remainder of the knowledge base is unaccessible and, for all intents and purposes, may as well not exist. This dependence of accessible knowledge on environment may be a significant factor in errors of omission or commission in the field. Considered from this point of view, the discriminating mark of true expertise may not be what is known but rather how the task environment is managed so that the induced contexts make relevant information accessible.

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knowledge structure capable of discriminating among contexts, a circumstance that would tend to produce uniformity in knowledge properties over the solution sequence. Finally, a very high level of automatic behavior would also indicate highly developed expertise.

APPENDIX A
CODED ACTIVITIES

Code	Activity	Description
Observable Behavior		
j=1	Information acquisition	Reading documents, receiving responses to inquiries
j=2	Requesting	Inquiry of those in the task environment who may have information or data
j=3	Calculating	Performing an original calculation or verifying a client-produced calculation
j=4	Writing	Writing memos or other narrative task related documents
j=5	Other	Organizing, indexing, searching, etc.
Mental Activity		
r=1	Automatic mental responses	Non-cognitively mediated transitions between observable behaviors
r=2	Analysis and planning cognition	Subject verbalizes information about the task, task environment, task objectives, or how to proceed in the task
r=3	Uncertainty cognition	Subject verbalizes uncertainty or confusion about the task, task environment, or how to proceed in the task

Notes: n_{rjt} indicates the frequency of mental activities of type *r*. mediating transitions to behavior of type *j* occurring during interval t. In equation (1), $n_{sjt} = \sum_{r=1}^{r=3} n_{rjt}$, accessible knowledge $n_{cjt} = n_{1jt} + n_{2jt}$, available knowledge $n_{vjt} = n_{1jt}$. n_{jt} indicates the frequency of behaviors of type *j* occurring during interval *t*.

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