ELECTRIC POWER RESEARCH INSTITUTE

Program on Technology Innovation: Accelerating the Achievement of Mission-Critical Expertise

A Research Roadmap

1016710

Program on Technology Innovation: Accelerating the Achievement of Mission-Critical Expertise

A Research Roadmap

1016710

Technical Update, December 2008

EPRI Project Manager

D. Ziebell

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

Institute for Human and Machine Cognition

Institute for Simulation and Training, University of Central Florida

Klein Associates division of Applied Research Associates

Perigean Technologies, LLC

This is an EPRI technical update report. A technical update report is intended as an informal report of continuing research, a meeting, or a topical study. It is not a final EPRI technical report.

NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

CITATIONS

This report was prepared by

Institute for Human and Machine Cognition
40 South Alcaniz Street
Pensacola, FL 32502

Principal Investigators
R. Hoffman
P. Feltovich

Institute for Simulation and Training, University of Central Florida
3100 Technology Parkway
Orlando, FL 32826

Principal Investigator
S. Fiore

Klein Associates division of Applied Research Associates
1750 Commerce Center Blvd. North
Fairborn, OH 45324

Principal Investigator
G. Klein

Perigean Technologies, LLC
8108 Lee Jackson Circle
Spotsylvania, VA 22553

Principal Investigator
B. Moon

This report describes research sponsored by the Electric Power Research Institute (EPRI).

The report is a corporate document that should be cited in the literature in the following manner:

Program on Technology Innovation: Accelerating the Achievement of Mission-Critical Expertise: A Research Roadmap. EPRI, Palo Alto, CA: 2008. 1016710.

PRODUCT DESCRIPTION

The problem of knowledge loss—the result of employees taking undocumented knowledge with them when they leave the workforce—has been well described and researched. But has the industry done everything it can to capture and transfer undocumented knowledge to other employees?

The research undertaken by the Electric Power Research Institute (EPRI) and described in this report indicates that most undocumented knowledge can indeed be effectively transferred through training, mentoring, and other proven processes. What remains unknown, however, is how long it takes recognized experts to accumulate their mission-critical expertise and whether that timeframe can be condensed. The goal of this project was to determine how methods for accelerating the achievement of expertise and extraordinary expertise might be taken to entirely new levels. What is it within the work itself that takes time to master? What is it about the nature of the cognition within the work that makes achieving high levels of proficiency an investment of many years?

The analysis presented in this report illuminates what is known about how expertise is acquired in domains that are both similar to and different from utility domains.

Results and Findings

Little is known about the kinds of expert judgment that are important in the utility domain. Therefore, it is not clear whether the methods of building expert judgment that have been documented in other domains are transferable to the utility industry. Expert technical judgment in the industry today is generally the result of unstructured, ad hoc sequences of experiences by relatively few individuals—the result of being in the right place to suitably experience rare and challenging events, repeatedly.

Typically, at least 25 years and an investment of hundreds of thousands of dollars in salary and training expenses go into the making of a recognized expert. Any years that can be shaved off of that would represent a significant savings and lessening of risk. One EPRI-member utility estimates that transferring its experts' undocumented knowledge to other engineers saves $100,000 in prevented failures. EPRI seeks to understand how the time to expertise might be reduced by a factor of three. The project described in this report also investigated how experienced utility personnel from one area of practice can become expert in a different area of utility practice in a matter of one or two years.

Challenges and Objectives

The research and theories presented in this report will be especially useful to the management and training personnel who are responsible for hiring, transferring, and educating the individuals who perform mission-critical functions in plants. The problems associated with the loss of expert knowledge and skill will only grow in severity under the strains of dramatic labor-force shifts that will see as much as 40–70% of the workforce retiring over the next 5 to 10 years.

Applications, Value, and Use

The roadmap provided in this report recommends several actions toward one or more demonstration projects. Among these actionable recommendations, surveys will bring issues of workforce and knowledge loss into focus at high levels of management and leadership within the utilities, moving discussion of the problem into an even finer grain of detail than current knowledge loss risk assessment approaches. Broad recognition of the problems and challenges will motivate continuing efforts to create a knowledge culture. Field studies and cognitive task analysis will begin a process of knowledge capture—revealing the knowledge, skills, and strategies of utilities experts—so that this expertise might subsequently be used in training. At the same time, field studies and cognitive task analysis will generate materials that can be used in attempts to accelerate the achievement of expertise, including tough case time compression and decision-making exercises.

EPRI Perspective

EPRI's contribution to the set of solutions for knowledge loss has focused on researching, developing, and testing practical tools for capturing valuable undocumented knowledge that utility personnel apply to bring sustainable performance to the utility. A 2002 report, *Guidelines for Capturing Valuable Undocumented Knowledge from Energy Industry Personnel* (report 1004663) develops the scope of the problem and surveyed methods to address it. *Capturing and Using High-Value Undocumented Knowledge in the Nuclear Industry: Guidelines and Methods* (report 1002896) provides a detailed process for effectively applying the methods. In *Real-Time Expert Knowledge Acquisition and Transfer—Needs and Technology Assessment: Toward Self-Elicitation and Automated Knowledge Capture Methods* (report 1009581), the process is updated, and additional insight on easing the flow of certain kinds of information from experts is provided.

Approach

This report has the following three purposes:

- To describe the researchable problem in general terms. How can we accelerate the rise to extraordinary levels of expertise of those technical experts tasked with handling the most difficult and mission-critical of technical issues?
- To differentiate the problem of loss of experts from the more general challenge of the aging of the workforce, which affects most utilities in nearly all mission-related activities. The knowledge management and training that meet the broad workforce challenge will do little, if anything, to minimize the risk to the utility mission posed by loss of critical experts.
- To establish a roadmap for completing the research to address the problem.

Keywords

Aging workforce
Knowledge management
Knowledge retention

CONTENTS

1 INTRODUCTION 1-1
- Background 1-1
- Purpose and Intent 1-2
- Method 1-2

2 THE PROBLEM OF EXTRAORDINARY EXPERTISE 2-1
- Expertise Domains Within the Utilities 2-1
- The Problem 2-2
- Approach 2-2
- Terminology 2-4

3 LITERATURE REVIEW 3-1
- Studies of Expertise in the Field of Psychology 3-1
- The Field of Training 3-2
- The Field of Educational Psychology 3-2
- The Field of Naturalistic Decision Making 3-2
- The Field of Knowledge Management 3-5
- Mentoring 3-7

4 APPLICATION OF PAST RESEARCH TO UTILITY DOMAINS 4-1
- Looking Again at the Specializations in the Utilities: Similarities with Conclusions from Expertise Studies 4-1
  - Time Scale 4-2
  - Coping with Changing Technology 4-2
- Looking Again at the Specializations in the Utilities: Selection Versus Training 4-3

5 INITIAL CRITERIA/SUCCESS FACTORS FOR A FINAL PROGRAM 5-1
- Theoretical Foundation 5-1
- Training Requirements 5-3
  - Training Must Minimize the Transfer Distance 5-3
  - Training Must Promote Flexibility and Adaptability 5-3
- Training Materials 5-4
- Training Procedure 5-5
  - Adaptability and Perceptual Learning 5-5
  - Reasoning Skills 5-5
  - Feedback 5-6
  - Time Compression 5-6
  - Decision-Making Skills 5-8
  - Teamwork Skills and People Skills 5-10

6 **THE WORKING MEETING..7-1**
Meeting Rationale 7-1
Characteristics of Experts and Superexperts 7-2
Defining Features of Experts and Superexperts 7-5
Organizational Context..7-8
Knowledge Loss Risk Assessment 7-9

7 **ROADMAP FOR ACCELERATING THE ACHIEVEMENT OF EXPERTISE........................8-1**
Trials and Demonstrations 8-1
Development of a Corpus of Case Studies of Superexperts and Experts in Action (Near-Term) 8-1
Survey of Utilities Managers to Overview Knowledge Management and Loss of Expertise (Near-Term) 8-1
Surveying Selection Methods of Potential Superexperts (Medium-Term)......................8-2
Field Research 8-2
Cognitive Task Analysis (Near-Term) 8-2
Continue Knowledge Capture from Superexperts (Near-Term) 8-2
Gathering and Cataloging Tough Cases (Medium-Term) 8-3
Selection Research (Based upon Surveying Selection Methods) (Long-Term).............8-3
Sharpen Feedback Given to Prospective Experts (Near-Term)....................................8-3
After-Action Reviews..8-3
Pre-Mortem 8-3
Training and Learning 8-4
Assess Barriers to Learning (Long-Term) 8-4
On-the-Job Training (Medium-Term) 8-4
Conclusion 8-4

A **REFERENCES..A-1**

B **TRANSLATED TABLE OF CONTENTS B-1**
繁體中文 (Chinese – Traditional)..B-2
简体中文 (Chinese – Simplified) B-9
Français (French)..B-16
日本語 (Japanese) B-22
Español (Spanish)..B-28

1 INTRODUCTION

Background

The problem of corporate knowledge loss, as people leave the workforce and take their undocumented knowledge with them, has been well described. A broad array of activities is underway in the utility industry. The Electric Power Research Institute's (EPRI's) contribution to the set of solutions has focused on researching, developing, and testing practical tools for capturing valuable undocumented knowledge that utility people use to bring sustainable performance to the utility. An early report, *Guidelines for Capturing Valuable Undocumented Knowledge from Energy Industry Personnel* (EPRI report 1004663) develops the scope of the problem and surveys methods to address the problem. *Capturing and Using High-Value Undocumented Knowledge in the Nuclear Industry—Guidelines and Methods* (EPRI report 1002896) provides a detailed process for effectively applying the methods. *Real-Time Expert Knowledge Acquisition and Transfer* (EPRI report 1009581) updates the process and provides additional insight on easing the flow of certain kinds of information from experts.

Since these reports, EPRI and others have gained experience in applying the methods. The question can now be asked—Have we done everything that needs to be done with respect to capturing and transferring undocumented knowledge? At this point, the answer is that for part of the problem, the research is done and the issue is one of implementation only. For another important part of the problem, some unknowns still exist. From EPRI's experience, it has become clear that there are two important parts of the overall scope of undocumented knowledge that need different treatments.

First, there is valuable undocumented knowledge that resides in the minds of many productive workers but is not written down for ease of transfer to new workers. This has been called *tribal knowledge* and, historically, has not been a big threat to continuity because the workforce changed only slowly. Tribal knowledge was the first problem to be identified with the retirement of the baby boomers, the harbinger of a new reality in which the workforce is turning over very rapidly and in which companies may not have time to let the new workers pick up the tribal knowledge at their own pace. Industry experience shows that the process of capturing undocumented knowledge and transferring it through relatively well-known processes—such as training and procedure improvement—works and that the issue is simply one of implementation.

Second, there is valuable and rare undocumented knowledge that resides in the minds of a very small number of experts, is not written down, and is vital to the success of the utility mission. EPRI's experience in applying the tools has resulted in capturing and transferring to specific identified people a large amount of such rare and mission-critical knowledge. In working with these situations, two unknowns have become obvious. It is unknown how long it takes for utility people to become one of these rare experts, and it is unknown whether that process can be sped up. This project was undertaken to investigate these two unknowns.

Purpose and Intent

This report has three purposes. First, this report describes the researchable problem in general terms. The researchable problem is the following question: How can we accelerate the rise to extraordinary levels of expertise of those technical experts who are relied upon by electric utilities to handle the most difficult and mission-critical of technical issues?

Second, this report differentiates this problem from other related and more general issues. The general problem is the challenge of the aging of the workforce. This is a broadband issue, involving an entire cohort of workers. The broadband challenge affects nearly all utilities in nearly all mission-related activities. The problem of particular interest in this report is a specific one: coping with the loss of an individual who performs difficult mission-critical functions. The activities of knowledge management and training that are necessary to meet the broad workforce challenge will do little, if anything, to address minimizing the risk to the utility mission if one of the critical experts were lost. Section 2 expands the discussion of these first two purposes.

The third purpose of this report is to establish a roadmap for completing the research to address the problem. The remainder of this report explains development of the roadmap.

Method

The effort leading to this report culminated in a working meeting of scientists and utility personnel. The end product of the working meeting was a roadmap for future research. The basis for the meeting was a white paper developed by the researchers early in the project. The white paper formed the basis for the scientists and utility people to compare perspectives, primarily by understanding the state of the research and the nature of the utility environment in which the need for extraordinary expertise arises.

This report is an expansion and evolution of the white paper. Sections 2–5 of this report were initially presented in the white paper.

This report adds new material in Sections 6 and 7 to describe the working meeting and to present the resulting roadmap. As such, this report may be read once through as an explanation of the basis for the roadmap.

2
THE PROBLEM OF EXTRAORDINARY EXPERTISE

Expertise Domains Within the Utilities

In the electric utility business, many technical positions are held by outstanding experts recognized as having a grasp of their field that far exceeds that of others. These technical positions are often depended upon for mission-critical, problem-solving prowess or the making of difficult and high-value technical judgments.

Example 1: An officer had decades of experience representing a company before a public service commission. He was the “go-to guy” because he had learned all of the right people skills and strategies and was thoroughly familiar with both the formal and the informal commission process, historical outcomes, political pressures, and the evolution of corporate strategy to meeting its regulated obligations.

Example 2: A safety engineer had conducted radiological analyses at three plants, across all decades of the plants’ existence. He could provide extremely detailed information about differences and similarities in the plants’ infrastructure and procedures and especially the forgotten rationale behind many company practices.

Example 3: A chief district operator was responsible for overall long-range planning and safety management to ensure the reliability of the world’s most complex electric distribution system. Technology upgrades, staffing and training, production pressures, and historical evolution of the complexity of the system were all in play continuously, all needing to be orchestrated in the face of changing conditions to guard the corporate mission of reliable and safe electricity distribution.

Among the mission-critical services rendered by these unique experts are the following:

- The expert provides technical judgment to speed corporate decision making in time-critical events, where customer service, individual safety, and large investments in equipment and money are at risk.
- The expert provides resilience to company operations by resolving problems, complexities, disasters, and so on; anticipating future demands; initiating plans that are implementable within the current environment; and acting prudently across longtime scales of action (where others might be more impulsive).
- The expert is a repository for vast historical information, often tacit, but just as often simply lost, buried in difficult-to-access locations.
- The expert understands a bigger picture and therefore exercises effective technical leadership in ambiguous or complex situations, often by communicating simple features that other people will not see until they are pointed out.

The Problem

One thing that can keep utility management awake at night is what to do when a key expert retires (EPRI 1012127). An example would be the chief district operator mentioned previously. He was regarded as a mission-critical resource by the company, and, as his retirement approached, the company had to devote urgent attention to the challenge of capturing his undocumented knowledge and skill. Key experts possess knowledge that is unique and critical to the company operations. Positions such as those previously exemplified are vital to the ongoing success of the utility because the expert deals with the complexity inherent in the utility business, in the utility bureaucracy, and in most emergent situations. A great many jobs in the utilities are ones where one expects to find resident expertise: distribution system operator, pipe-type cable engineer, system relay protection engineer/manager, distribution engineer, specialized billing managers, and many others.

There is a classic estimate that the development of very high-level skill in any complex area takes at least 10 years (Hayes 1985). However, routine practice is not sufficient for the development of expertise. There needs to be the following:

- A constant stretching of the skill, defined by increasing challenges (tough or rare cases)
- High levels of intrinsic motivation to work hard on hard problems
- Practice that provides rich, meaningful feedback
- Practice based on mentoring (for the apprentice-to-journeyman progression) or on some form of more expert instructional guidance (for the journeyman-to-expert progression)

Practice characterized in this way has been termed *deliberate practice* (Ericsson 2006). These findings about expertise hold for domains ranging from musical performance to world-class sports performance to scientific and engineering domains.

EPRI's observation of experts in utility domains affirms that it takes a long time to achieve expertise and also that extraordinary experts who conduct mission-critical activities are recognized as having achieved their extraordinary respect and value after 25–35 years of experience. Of course, many people in the utility workforce, including management, currently have 25–35 years of experience, but the large proportion of the utility personnel are not recognized as having expertise that vastly exceeds that of others. The large proportion of utility personnel have simply become very good at what they do.

This empirical fact about expertise (it takes a long time) sets the stage for this EPRI effort. What is it within the work itself that takes time to master? What is it about the nature of the cognition within the work that makes it take time to achieve high levels of proficiency? The analysis that follows will illuminate what is known about how expertise is acquired in domains that are both similar to and different from utility domains.

Approach

What is it about utility domains of expertise that make it difficult to achieve extraordinary levels of expertise?

Early in this project, in preparation for the working meeting, we identified two categories of expertise. We have used the phrase *extraordinary experts* to denote those people who have a capacity exceeding that of others—who are depended upon for mission-critical, complex technical guidance or high-stakes decision making. We will use the term *experts* to denote those individuals who are superior performers in the course of expected situations, that is, the majority of utility personnel filling productive roles across the industry.

This distinction is necessary because the time to expertise generally seen across the utility industry is 25–35 years, but it is clear that mere time in grade does not enable just anyone to adequately fill a truly unique and mission-critical function. Indeed it is possible, although unconfirmed, that most highly experienced experts seen in the industry have been in that status for the last 15–25 years of their employment. This would be consistent with the scientific conclusion about how long it takes for people to achieve expertise. But it does not explain how or why rare individuals gain command over the same domains of activities that far exceed the abilities of the other, more common, experts.

This bifurcation suggests two useful lines of research. First is the question of whether the achievement of extraordinary expertise can be accelerated. What might be the payoff to utilities if this problem were solved, say, by reducing the 25 years to 10 years? The window of risk, where loss of a particular expert could hurt the company's mission, could be reduced by accelerating the progression to extraordinary expertise by another individual. This is the line of research of most interest in this report, and the roadmap presented in Section 7 is the culmination of this effort to date.

The second line of research is broadband: the achievement of proficient expertise among wide populations. Clearly, the demographic wave sweeping the industry will require large numbers of replacement personnel who are highly proficient at their jobs, and some of these replacements must be individuals who have achieved the status of experts. Can we reduce the time it takes to make experts?

Current industry broadband efforts include hiring large numbers of replacement personnel, gearing up training programs that have been idle, and working with government and academia to develop the workforce. Much of the broadband effort also includes knowledge management issues, such as improved access to information and potential advances in educational technology, and redesign of the workplace.

The second line of research would be an extension of otherwise normal human resources, training, and information management processes. These normal processes, in large measure, are aimed at ensuring that the trained workforce meets minimum acceptable standards of qualification but not necessarily the achievement of expertise. The value of this report to people interested in this second line of research is that in surveying expertise studies, our investigation touches on many aspects of relevant research, seeking to tease out those research results that are constructive of the main line of research we seek. Section 5 of this report may be considered the culmination to date of this second line of research because it contains many lessons from expertise studies that are applicable to improving these normal processes.

In summary, methods for accelerating the achievement of expertise and extraordinary expertise might be taken to entirely new levels. This is the goal of this report.

Terminology

The meaning of terms such as *apprentice* and *expert* within the utilities differs from academic usage. Because this report attempts to form the basis for clear communication between the academic and utilities communities, the reader must bear this difference in mind. The two usages are neither right nor wrong, yet care is necessary to understand the points being made from the different perspectives. In the utilities, *journeyman*, *expert*, and *master* are terms associated with craft activities and not with activities such as engineering, operations, customer service, fault analysis, planning, and the myriad non-craft activities that utilities carry out. In expertise studies, *journeyman*, *expert*, and *master* are related not to the activity but to a progression of stages in the acquisition of any form of expertise.

This report assumes two kinds of experts that can be meaningfully differentiated: experts versus extraordinary experts. This distinction reflects the idea of the *superior expert* or the *1-percenter* that has been used in the academic literature. If the distinction reflects a real difference in quality, making the distinction helps us focus on our researchable problem.

In the next section, we survey the main scientific approaches/methods/theoretical frameworks that are pertinent to a scientific answer to the question of acceleration. These include the psychology of training and transfer, educational psychology, the field of instructional design, the modern field of expertise studies, the modern work of naturalistic decision making, and the field of knowledge management.

3
LITERATURE REVIEW

During the Middle Ages and Renaissance, the craft guilds had well-specified procedures for the transmission of knowledge and gave us the developmental scale that is still widely used: initiate, novice, apprentice, journeyman, expert, and master (Hoffman 1998). Based upon interviews and observations of the workplace, Denis Diderot created one of the great works of the Enlightenment, the 17-volume *Le Encyclopédie* (Diderot 1751–1772), which explained many secrets—the knowledge and procedures used by experts in a number of trade crafts.

Studies of Expertise in the Field of Psychology

Modern psychology includes studies of different stages during the acquisition of skill (Chi, Feltovich, and Glaser 1980). The research emphasized problem-solving behaviors decomposed as learning hierarchies (Gagné and Smith 1962), that is, sequences of learning tasks arranged according to difficulty and direction of transfer. In the 1980s, a new stream of research began, involving studies in which highly skilled, domain-smart participants engaged in tasks that were more representative of the complexity of the real world in which they practiced their craft (Knorr-Cetina and Mulkay 1983; Shanteau 1992). This included exploration of human capabilities for making decisions, solving complex problems, and forming mental models (Hutchins 1995; Lave 1988; Scribner 1984).

The research has led to consensus on a methodology for studying experts, referred to as *cognitive task analysis*. We know the strengths, weaknesses, efficiencies, appropriate uses, and limitations of a variety of methods for revealing experts' reasoning and knowledge (Crandall, Klein, and Hoffman 2006).

The research has also led to consensus concerning the defining features of expertise. Experts are distinguished by virtue of their rich and highly organized knowledge, their skill in applying procedures and creating new procedures, their ability to cope with tough or challenging cases, and their ability to perform under stress and high levels of mental workload (Hoffman 1998).

Experts work in complex sociotechnical contexts, they come to work already knowing a great deal, and they are confronted with complex and challenging tasks. In contrast, the typical aims for training the less advanced individual are, minimally, that learners will retain what they have learned beyond the training sessions, shown as gains in measurable performance. Ideally, the learning experience provides a springboard for a capability to address new kinds of problems and challenges beyond those involved in the training and for fostering the further development of learning.

The Field of Training

Historically, the psychology of learning has focused on classroom learning contexts. This contrasts with the cognitive efforts required in real-world domains of expertise, described as follows:

> Training should help individuals to develop adequate mental models of typical problems in the domain and to choose the most appropriate strategy. Training should focus on domain-specific knowledge as well as on abstract planning and evaluation strategies. Effective communication and cooperation skills should be taught and deepened through practical exercises. (Sonnentag et al. 2006, p. 384)

The Field of Educational Psychology

The educational philosophy of John Dewey (1916) advocated learning by doing and emphasized the development of critical thinking skills through problem-solving exercises. A notion of experiential learning (the acquisition of knowledge and skill by learning through the sharing of experiences) may be useful in expertise acceleration. It is often assumed that the way to help learners cope with complexity is to simplify the situation and then incrementally introduce increasingly complex elements. However, initial learning that is more difficult can lead to greater flexibility and transfer. Research on high-end learning (for example, in medical education) has shown that when learners are initially exposed to simplifications of complex topics, serious misunderstandings can remain entrenched and interfere with or preclude deeper, more accurate understandings (Feltovich, Spiro, and Coulson 1993).

Constriction can also be found in the subspecialization of expertise—expertise can be greatly limited in its scope of application (Ericsson et al. 2006; Elstein, Shulman, and Sprafka 1978; Feltovich and Barrows 1984). This is to say that the learning and training styles that the utilities industry is accustomed to may be insufficient to foster the rise to expertise and extraordinary expertise.

The Field of Naturalistic Decision Making

Researchers in these fields study complex problem solving by experts in a great variety of domains, including firefighting, nursing, weather forecasting, electronics troubleshooting, and many others (Flin et al. 1997; Hoffman 2007; Klein et al. 1993; Klein and Zsambok 1995; Salas and Klein 2001).

Differences and similarities can be seen comparing domains of expertise to utilities specializations with regard to the types of problems experienced by key utility experts—especially extraordinary experts. At the most general level, we similarly see complex problems being described as a type of situated unknown that has associated with it multiple conflicting goals and a number of solution methods (Jonassen 2007), and knowledge associated with the problem is distributed across a variety of people with varied interests.

Differences and similarities can be seen comparing domains of expertise to utilities specializations with regard to problem-solving strategies. The situational nature of problem solving often makes the problem-solving task difficult in ways similar to EPRI's experiences, in that legacy systems sometimes create troubleshooting problems when interacting with modern devices. Along these lines, another similarity is the use of historical information that provides the rationale or justification for practices, decisions, procedures, and so on.

Experts sometimes cannot engage in deliberative analysis of options. In emerging, high-stakes, time-pressured situations, there is no time for rational analysis of options, costs, or risks. The normative decision theory argues that problem solving can be optimized only if a rational analysis is conducted. But such analysis is precluded in time-pressured situations. Studies of firefighters, nurses, managers, and other domain experts have shown that experts more typically engage in recognition-primed decision making. In this process, an inspection of information leads directly and immediately to a path of action, and, typically, the first option selected by the expert is the optimal or best one. Analogous to recognition-primed decision making, we find that a failure diagnosis in the utilities typically involves comparing current symptoms to prior experience.

There have been observations of utilities expertise that suggest that recognition-primed decision making occurs as a strategy for work. The chief district operator to whom we referred in Section 2 often used recognition-primed decision making to set the course of a department-wide analysis (that in the end would prove his instant response was right), then told people what to do immediately (his initial response). That he did this for almost everything that crossed his desk for action amazed his coworkers.

Utility experts also often engage in deliberate analysis. Perhaps it is part of the path to extraordinary expertise to choose to engage in deliberate analysis. Perhaps individuals are forced into deliberate analysis by events or by questions from management. Certainly, most utility events do not play out at the pace of other classical examples of expertise in action, such as the skill-based expertise exemplified by sports superstars.

Differences and similarities can be seen comparing domains of expertise to utilities specializations with regard to job type. Many utilities specializations involve high-level or managerial decision making, and naturalistic decision making researchers have extensively studied expert managers and executives (see Klein 2003). A key finding that might transfer to the utilities has to do with the ways managers convey their intent to their subordinates. The expression of intent can best support teamwork if it captures key goals, certainly, but also if it expresses things to look out for and things to avoid (in Klein's scheme, these are called *anti-goals*). The naturalistic decision making work on expertise at high-level decision making might be applied in the study of utilities specialists whose job primarily involves decision making.

Differences and similarities can be seen comparing domains of expertise to utilities specializations with regard to technology. Dimensions would include the newness of the technology (for example, new software versus legacy systems) and the extent to which workplaces and jobs depend on information technology. In some utilities specializations, information technology is not the critical aspect of the job (for example, liaising to a public service commission), whereas in others, it is (for example, bulk power coordination). In some specializations, the work involves high-level cognition and also tough physical work (for example, turbine maintenance). For example, in the case of the responsibilities of a chief district operator, we see a complex interplay between legacy systems—sometimes decades old—and modern systems, as well as systems that literally extend for hundreds of miles. The confluence of these factors drives a need to understand dynamic interactions within a system of systems as well as how external factors (for example, weather conditions) can affect management and maintenance of these varied systems.

Differences and similarities can be seen comparing domains of expertise to utilities specializations with regard to teamwork. A study of expert software engineers by Sonnentag (2000) showed that experienced problem solvers place a high value on cooperation and engage in more work-related communication. The problem-solving process in many utilities specializations relates clearly and directly to team cognition research in areas such as software development, system administration, and design teams. These range from somewhat homogeneous teams, such as in software development, to often heterogeneous teams, such as in systems administration. However, these teams are all created to develop, manage, and maintain some complex technological product or system.

In the context of maintenance, and from the collaborative standpoint, what are similar are instances where teamwork has to serve differing parts of the problem-solving process. First, there is a need to recognize that a problem has occurred followed by the need to define and represent that problem, culminating in discussions about generation and testing of particular solutions. Critical to these processes is information sharing, in that the heterogeneous nature of the team's knowledge and/or the particular roles they are playing require efficient passing of data. The distributed nature of the work is somewhat similar in that all members of a team may not be collocated and data from the field can be coming from technicians on the ground. As with other team cognition research domains, this complicates the collaboration in that it introduces some ambiguity to the problem-solving process.

Perhaps the critical difference in the utilities is the ad hoc nature of the teams and how the teams get assembled. That is, once a problem is recognized, a team is assembled by the chief district officer, or similar other, based upon his or her initial assessment of the problem. First, having the rights to assemble a team is somewhat unique in that teams typically already exist. Second, related to this but from a collaborative standpoint, this means that the team may have little or no history working together, which can influence information sharing and recognition of expertise early in the process.

In his analysis of system administrators, Haber describes a similarly complex problem-solving environment, noting that they often consist of a multitude of components ranging from "HTTP servers, web application servers, authentication servers, content servers, database management systems, network load balancers . . . distributed across multiple networks and multiple operating system platforms, and each of the components may have hundreds or thousands of configuration parameters" (Haber 2005, p. 1). Thus, similar to the power industry, in the course of troubleshooting these systems, one needs to comprehend how all of these varied components interact and to integrate system information into a single picture.

From the standpoint of team cognition, this task consists of a dynamic social-cognitive process requiring diagnostic interrogation of the system and diagnostic questioning of the oftentimes ad hoc team. Haber refers to this as *group sense making*, and, although he does not address problem recognition, he describes their problem definition and solution processes. Specifically, he notes that a "problem existed due to interactions between the components of a very complicated system, and the experts on the different components needed to work together to understand the cause and find a solution. The overall strategy was a cycle of shared observations of the system in question, developing hypotheses as individuals, small groups, or the group as a whole, and implementing changes to attempt a fix" (Haber 2005, p. 3). Maglio et al. (2003) similarly discuss computer systems administration from a perspective of complex problem solving, also noting the social-cognitive nature of the collaboration. They describe a requirement for developing common ground and the coordination of attention across a number of team members, ranging from engineers engaged in troubleshooting, technical support personnel, and software application developers.

But what may be different with respect to the utilities is the emphasis on cooperation strategies that are used in system administration. The work places high cognitive demands on practitioners "as system administrators troubleshoot systems, making sense of millions of log entries by controlling thousands of configuration settings, and performing tasks that take hundreds of steps. The work also places high social demands on practitioners—as systems administrators need organizational and interpersonal skills to coordinate tasks and collaborate effectively with others" (Barrett et al. 2004). Related to this, Sonnentag and Lange (2002) found that among engineering and software development teams, a general knowledge of cooperation strategies, that is, what to do in situations requiring cooperative behavior, is related to better performance. Cooperation is more valued by the experts than by the moderate-level performers. Experts engage in higher amounts of work related communication, help their coworkers, and seek out feedback from coworkers (Sonnentag 2000).

The team leader can play a critical role in complex problem-solving teams, enabling (or obstructing) information sharing and coordination. The team structure and conflicting team member goals and roles can sometimes impede problem solving:

> Various people participated in troubleshooting, but only George had access to the system. His manager wanted to know when the problem would be fixed and whether others should be redirected to help him complete the task on time. The support person wanted to resolve the problem ticket and end the call as quickly as possible. His colleague wanted to help within the limitations imposed by his own responsibilities. The system architect wanted to know if there was any problem in the overall design without being mired in the details. Other specialists waited for instructions to manipulate the subsystems they were responsible for. The problem was eventually found to be a network port misconfiguration. George misunderstood the meaning of a certain configuration parameter for the new web server. George's misunderstanding affected the remote collaborators significantly throughout the troubleshooting session. (Haber 2005, p. 4)

The Field of Knowledge Management

The early work on expert systems led to the vision that organizations might create large knowledge repositories (Becerra-Fernandez and Leidner 2008). Knowledge management software systems differ from traditional management information systems in that knowledge management software tools help create the very content on which they operate. Like traditional management information systems, however, there are issues of acceptance and integration into business procedures and organizational cultures.

Over the years since Klein's seminal publication *Preserving Corporate Knowledge* (1992), numerous articles and trade books have appeared, bearing such titles as *If We Only Knew What*

We Know (O'Dell and Grayson 1998) and *The Knowledge Creating Company* (Nonaka and Takeuchi 1995) (see also Allee 1997; Brooking 1999; Choo 1988; Davenport and Prusak 1998; Lambe 2007; Leonard and Swap 2005). All of these discuss expertise (or core competencies), knowledge elicitation, and knowledge repositories. These books illustrate what some see as the knowledge management craze of the late 1990s, "when upwards of 25 percent of Fortune 500 companies had a Corporate Knowledge Office" (Pringle 2003). Organizations such as IBM and the World Bank have made substantial investments in support of organizational knowledge capture and management. Norman Kamilkow, editor of *Chief Learning Officer Magazine*, said,

> What we saw was that there is a growing role for a chief learning officer type within enterprise-level companies . . . there is a need to have somebody focused on how to keep the skills of the corporation's work force at a high level. (quoted in Pringle 2003, p. B1)

In the knowledge management process, company management establishes a program whereby experts who possess valuable undocumented knowledge collaborate with a knowledge engineer. Working together, they elicit the worker's wisdom for inclusion in the organization's knowledge base. In extreme cases, such as a senior worker retiring, the individual might be retained or brought back as a consultant (Becerra-Fernandez and Leidner 2008).

The field of knowledge management raises the practical problem of knowledge finding—identifying individuals who possess knowledge that is the following:

- Unique to them
- Critical to the organization
- Tacit in the sense of being undocumented

This has been recognized as a key to the success of knowledge management broadly (Gaines 2003; Gross, Hanes, and Ayres 2002; Hanes and Gross 2002). Recent experience shows that it is possible and sometimes fairly easy for experts and managers, working together, to identify the unique and important knowledge areas in which a particular expert excels. Likewise, domain practitioners can readily identify those important concepts in a domain that seem to be especially difficult for others to fully comprehend (Dawson-Saunders et al. 1990). A critical gap, however, is that a robust, general procedure for doing this has not been formulated in such a way that anyone might implement it.

Knowledge-intensive organizations rely on decision makers to produce mission-critical decisions based on inputs from multiple domains (Becerra-Fernandez et al. 2004). The decision maker needs an understanding of many specific subdomains that influence the decision-making process, coupled with the experience that allows quick and decisive action based on such information (Nonaka and Takeuchi 1995).

An additional recent awareness is that knowledge management by knowledge capture and knowledge repositories is only a part of the solution to workforce problems. "If an organization could capture the knowledge embedded in clever people's minds, all it would need is a better knowledge-management system. The failure of such systems to capture tacit knowledge is one of the greatest disappointments of knowledge-management initiatives to date" (Goffee and Jones 2007). What is needed in addition to knowledge management are new approaches to knowledge training, in particular, a method for accelerating the achievement of expertise. This links directly to the motive and goals of this report.

Mentoring

That much knowledge is transferred to or constructed within learners—from novices to advanced studies—is undeniable. However, much of what is known about learning refers to lower levels of cognition and has not been demonstrated at the higher levels of expertise and extraordinary expertise.

Workforce trends are raising the stakes with regard to on-the-job training and mentoring. Increasing complexity, pace of change, pace of decision making, and increasing worker mobility all entail fewer opportunities for mentoring (Becerra-Fernandez, Gonzalez, and Sabherwal 2004). Because of these trends, national policy is being formulated to support research and development in an educational infrastructure capable of producing the next generation of the science and technology workforce (see Committee on Science, Engineering, and Public Policy 2006). Even if such initiatives are successful, the results will be far too distant to help solve the immediate utilities workforce issues.

In some of the craft guilds of the Middle Ages, a *master* was any practitioner who was qualified to teach, in recognition of the special qualities that a good mentor must possess (Hoffman 1998; Renard 1968). Thus, even a journeyman could be qualified as a master. Naturalistic decision making has approached the nature of a good mentor. In *Sources of Power*, Klein (2003) described the kinds of techniques that skilled mentors use and the kinds of skills mentors need to develop for diagnosis, presentation of material, and setting the right climate for learning. There is some research on what makes for a good mentor in the sense of coaching in sports (Fiore and Salas 2008), and there is a large body of literature on what makes for a good teacher (Mistrell 1999; Proctor and Vu 2006). But little is known about what makes for a good mentor in the context of the modern sociotechnical workplace. Little is known about how to mentor individuals in the progression from journeyman to expert.

The issue is who would be an expert mentor, that is, what are the characteristics of the person who is both a domain expert and an expert at teaching the domain to others? The mentor knows how to create appropriate learning content and guide those who are less experienced. The expert mentor can rapidly form a rich mental model of the learner's knowledge and skill. From this, the expert mentor can predict when and why the learner will form a simplistic or inaccurate understanding. The mentor anticipates the kinds of cases that will lead the learner to err and the kinds of practice experiences that will push the learner to go beyond his or her current level of understanding of complexity (Hoffman 1998). Effective mentors use a modeling approach where appropriate actions and decisions are illustrated in the context of the actual operational environment, and, when warranted, the learner is guided in his or her own performance. The apprentice works with the expert to solve particular problems, while also making explicit the strategies being adopted as well as the apprentice's knowledge and reasoning.

Klein (2002, 2003) has observed mentoring activities in the job context. The mentor does the following:

- Establishes a relationship and environment that fosters learning
- Diagnoses the reasons why the trainee is struggling
- Tailors instruction to fit the situation

The best mentors accomplish all three. They have a repertoire of strategies for getting material across (for example, demonstrating the task while thinking out loud, interrogating the trainee for the rationale behind actions, and asking the trainee to instruct them). Less effective mentors or coaches usually have a very small repertoire—often, just a single or rote learning mode of lecturing to the trainee about the procedures to be followed.

The expert mentor can play an active role not only in on-the-job learning, but also in guided learning as would take place in simulation-based training episodes. This could be implemented with simulation-based environments or practiced in the work setting. There have been few studies of this (for example, Collins, Brown, and Newman 1989; Schaper and Sonnentag 1998), but both affirm the proposed description of mentoring.

There is an outstanding practical need for methods for rapidly identifying individuals having the most experience in the role of mentor and then cognitive task analysis to reveal the reasoning strategies of mentors, especially as they deal with mentoring situations that are challenging. The motivation of experienced workers to pass along their tough case knowledge is frequently there, but due to the bureaucratic habit of expecting that mentoring will succeed, they are often left not knowing how to proceed, or even knowing that their tough case knowledge is critical and highly informative to apprentices.

4
APPLICATION OF PAST RESEARCH TO UTILITY DOMAINS

Little is known formally about the kinds of expert judgment that may be important in the utility domain. Therefore, it is not known whether methods of building expert judgment discovered in other domains are transferable to the utility domain. Expert technical judgment in the industry today is generally the result of unstructured, ad hoc sequences of experiences by relatively rare individuals. It appears likely that this rarity is the result of being in the right place repeatedly to suitably experience rare and challenging events. As a result, typically, 25 years or more go into the making of a recognized expert. EPRI seeks to understand how to reduce that time by a factor of three and how prepared, experienced utility personnel from one area of utility practice can become expert in a different area of utility practice in an even shorter period (one to two years).

Looking Again at the Specializations in the Utilities: Similarities with Conclusions from Expertise Studies

What are the differences and similarities between the specializations in utilities and the domains studied in expertise studies and naturalistic decision making? Shared themes include the pervasiveness of tacit knowledge, the importance of anticipatory thinking, the centrality of knowledge and reasoning in the formation of rich understandings (so-called *mental models*). Comments made by subject matter experts in utilities domains who have participated in knowledge elicitation echo findings from expertise studies and in naturalistic decision making. There is wide recognition of the importance of detailed, highly organized knowledge. For instance, an expert on pipe-type cable design said “It is hard to pass on [this detailed knowledge] without the 101 course.” Of course, there is no such thing as a 101 course on pipe-type cable engineering.

There is also wide recognition that reasoning skill is critical to expertise. In a series of interviews with a top expert on off-normal relay events, another system protection engineer compared his results to those of this extraordinary expert and said, “It looks like he just goes to the correct answer and then assembles the facts to prove it. I don’t need his thought process so much as I need to know what he knows. Without that, we just muddle through.” This expert acquired his understanding of the intricate interrelations among the various components, systems, support groups, and disciplines over the course of his career. What is difficult to see is that the difference between muddling through and the expert’s results is not vast quantities of simple factual knowledge; rather, it is specifically the ability to rapidly understand the big picture—a mental model that allows them to comprehend and anticipate unfolding situations, somewhat in the manner of recognition-primed decision making (EPRI 1012127).

This necessary combination of knowledge and reasoning shows clearly in reports on expertise in the utilities:

> During early discussions of hydraulic event response, it became apparent that responding to alarms is problematic for inexperienced engineers and that much tacit knowledge is needed to simplify a response to alarms. The tacit knowledge used by experienced engineers consists of an understanding of the overall system—not just the local component or even the local pumping plant—from which the experienced engineers draw their understanding of possible causes for the symptoms that are presented to them (the big picture). The experienced engineers also have historical operating experience and a hands-on perspective (the ability to visualize the actual pumping plant) that comes from having been in many, if not all, of the pumping plants. (EPRI 1012127)

We also see some differences when comparing the utilities to other domains. We take these to represent novel and highly challenging aspects of this project.

Time Scale

Utility domains where extraordinary expertise is mission-critical are domains in which the feedback cycle for any intervention by the expert is very long—months or, in many cases, years. This is different from historical perspective, which is based on knowledge of things over historical time. For example, a transmission system relay protection expert had to determine which preventive maintenance tasks could be deferred during a budget crunch. This is an extraordinarily difficult decision. Many relays are maintained or calibrated, but once in several years, others require annual testing. But the same relay type may be installed in a range of critical and noncritical applications. Perhaps in some geographical areas, the relay types were used differently or maintained differently in their history because of mergers and acquisitions, different labor unions, or different state and local regulatory agencies. And every year, some things are deferred. At what point is the utility going to be exposed to truly elevated risk of failure if the preventive maintenance is not performed?

The point of this example is that the outcome of this difficult decision is not going to play out for several preventive maintenance cycles, and even seeing the effects of the decision is going to take extraordinary perspicacity.

In general, utilities are vast, lumbering machines embedded in a complex sociotechnical context. They change only slowly. This creates a problem when applying laboratory methods for the study of expertise in the utility contexts.

Coping with Changing Technology

From a performance and training standpoint, the existence in many utilities of a mixture of new and legacy technological systems (cognitive systems made up of a mix of old and new technology and work methods) is perhaps the most unique element of utilities specializations compared to other domains that have come under scrutiny by researchers. Although apprentice engineers may be well-educated in modern technology, it is unlikely that they will have training in legacy systems or in the interaction (or breakdowns in interaction of legacy systems with modern devices). It is likely that apprentices are not informed of the rationale for "why we did it this way." EPRI refers to this as *historical perspective*. The expert operations and maintenance specialist possesses a mental outlook over time, an experiential knowledge or hands-on familiarity, developed from years of experience coping with the injection of new technologies into the workplace, and through experiencing the interactions among legacy and modern devices. Because of this, they often have insights into particular problems that others (even advanced journeymen) might not see. It is this historical perspective that presents a challenge and perhaps one of the most important training targets.

Looking Again at the Specializations in the Utilities: Selection Versus Training

There are two critical components to Ericsson's expert performance approach (see Ericsson et al. 2006). First, it defines *expertise* as superior performance at representative tasks conducted under controlled circumstances. Although this measurement definition is important from the standpoint of research, it does not adapt well to application situations where the expert's performance cannot be brought under laboratory control. Furthermore, it ignores another critical aspect of the conceptual definition of expertise: that experts can perform well in rare, tough cases.

The second element of Ericsson's approach is the finding that expertise is achieved only after many years of sustained and motivated effort at deliberate practice. Taken together, these seem to suggest that the achievement of expertise cannot be accelerated to be less than the 10-year rule of thumb.

However, we find a lack of research on training at the high end of proficiency. Interestingly, the Ericsson et al. (2007) *Cambridge Handbook of Expertise and Expert Performance* includes no discussion of training or training issues. Indeed, the theme of Ericsson's definition of expertise—that it takes years of deliberative practice to achieve expertise—seems to militate against a consideration of training issues. This links directly to the core problem motivating the present report.

Perhaps it is possible to base training on Ericsson's notion of deliberate practice, not just to accelerate the progression from journeyman to expert, but also that from expert to extraordinary expert. Perhaps the general and broadband methods can be systematically made to fit the idiosyncratic nature of extraordinary experts—to individualize standard psychological and design principles to systematically create deliberate practice opportunities for utilization by motivated candidates. Perhaps this could improve on the only other form of individualized development that is available at the highest levels of expertise, that is, mentoring.

In many utility contexts, training does not proceed until after a selection process that winnows out people lacking necessary aptitudes. Often, then, training using standard methods results in a suitable population of qualified people to perform routine tasks. But after the basic population is chosen, the selection of internal candidates to work on difficult problems, and perhaps become extraordinary experts, is ad hoc. EPRI's experience has been that extraordinary experts become extraordinary because of the following:

- Personal choice to become a student of what interests them
- A lack of barriers to their success
- Some form of positive feedback that encourages their success

This finding fits with results of studies of expert weather forecasters by Pliske et al. (2004) and Hoffman et al. (2000). Hoffman found it highly common for weather forecasters to report an early fascination with the weather, leading (in adulthood) to an intrinsic motive to continue learning and developing higher levels of skill. Pliske et al. found that some forecasters were highly proficient or competent but had a proceduralist attitude of going through the steps in their job, whereas others had a scientist attitude marked by a desire to keep learning and getting better. Neither study, however, speaks directly to the matter of selection.

These findings are certainly suggestive of factors to consider in selection: the shaping of aptitude, attitude, or motivation in order to make it easier to create new extraordinary experts and an institutional culture that rewards such attitudes. Our focus now is on the ideas that inform a process of accelerating the achievement of expertise.

5

INITIAL CRITERIA/SUCCESS FACTORS FOR A FINAL PROGRAM

Findings in expertise studies and naturalistic decision making not only reveal key aspects of expertise but also suggest ways of accelerating the achievement of expertise or at least improving training through recognition of the key phenomena and high-level cognitive factors. This section presents results that are applicable to both broadband training efforts and efforts to speed the acquisition of extraordinary expertise. They were distilled from the literature review before the working meeting and were available to the working meeting participants as part of the basis for discussion.

Theoretical Foundation

Two theories that have emerged from expertise studies and naturalistic decision making can inform an attempt to accelerate the achievement of critical expertise: cognitive flexibility theory and cognitive transformation theory.

Research on how people deal with difficult, challenging cases (for example, Feltovich, Spiro, and Coulson 1989; Feltovich, Coulson, and Spiro 2001) led to cognitive flexibility theory, which identifies characteristics of problems that cause cognitive difficulty for learners but not for experts. The dimensions of difficulty are the following:

- Static versus dynamic. Are important aspects of a situation captured by a fixed snapshot, or are the critical characteristics captured by the changes from frame to frame only? Are phenomena static and scalar, or do they possess dynamic characteristics?
- Discrete versus continuous. Do processes proceed in discernible steps, or are they unbreakable continua? Are attributes describable by a small number of categories (for example, dichotomous classifications like large/small), or is it necessary to recognize and use entire continuous dimensions (for example, the full dimension of size) or large numbers of categorical distinctions?
- Separable versus interactive. Do processes occur independently or with weak interaction, or is there strong interaction and interdependence?
- Sequential versus simultaneous. Do processes occur one at a time, or do multiple processes occur at the same time?
- Homogeneous versus heterogeneous. Are components or explanatory schemes uniform (or similar) across a system—or are they diverse?
- Single versus multiple representations. Do elements in a situation afford single (or just a few) interpretations, functional uses, categorizations, and so on, or do they afford many? Are multiple representations (for example, multiple perspectives, schemas, analogies, case precedents) required to capture and convey the meaning of a process or situation?

- Mechanism versus systematism. Are effects traceable to simple and direct causal agents, or are they the product of more system-wide functions? Can important and accurate understandings be gained by understanding just parts of the system, or must the entire system be understood for even the parts to be understood well?
- Linear versus nonlinear causation. Are functional relationships linear or nonlinear (that is, are relationships between input and output variables proportional or nonproportional)? Can a single line of explanation convey a concept or account for a phenomenon, or are multiple overlapping lines of explanation required for adequate coverage?
- Universal versus conditional. Do guidelines and principles hold in much the same way (without the need for substantial modification) across different situations, or is there great context-sensitivity in their application?
- Regular versus irregular. Is a domain characterized by a high degree of routinization or prototypicality across cases, or do cases differ considerably from each other even when they are called by the same name? Are there strong elements of symmetry and repeatable patterns in concepts and phenomena, or is there a prevalence of asymmetry and absence of consistent pattern?
- Surface versus deep. Are important elements for understanding and for guiding action delineated and apparent on the surface of a situation, or are they more covert, relational, or abstract?

When a learner is confronted with a problem that involves dynamics, interactivity, nonlinear causation, and so on (the right-hand members of the previous dualities), and yet understands the domain in terms of separable, simple concepts and linear causation (the left-hand members of the previous dualities), the learner is likely to err. When confronted with the gaps and inaccuracies in their knowledge or reasoning, the learner is likely to invoke a *knowledge shield* that allows him or her to preserve a simplistic understanding in the face of contradictory evidence.

This links to the key notion of cognitive transformation theory (Klein and Baxter 2006). Cognitive transformation theory describes the changes to knowledge and reasoning that proficient workers need to undergo in order to make the jump from mere proficiency to superior levels of expertise. After a certain amount of learning and experience, people become adept at explaining away evidence that should help them realize the limitations of their mental models (by employing the knowledge shields). Some workers stagnate as their performance asymptotes because they are so effective in defending flawed mental models. Cognitive transformation theory argues for the importance of unlearning—experiences that force people to lose faith in their mental models so that they can move to the next level.

These core ideas of cognitive flexibility theory (what makes problems difficult for learners and the simplistic understandings that result for those learners) and cognitive transformation theory (the need for unlearning experiences) are certainly pertinent to shaping any program of accelerated learning.

Training Requirements

Training Must Minimize the Transfer Distance

A recurring theme from interviews of experts' problem solving was summarized in the working meeting by EPRI's David Ziebell:

> The expert knows there is no substitute for going out to look at the problem yourself . . . out there smelling the ashes. [We need to] bottle these experiences to simulate them . . . [the] look and feel and smell of critical events is what defines the problem.

The modes and means of training should engage real work practice, the challenges, contexts, and duties of the job, to the extent possible. In the language of psychology, training should be a short transfer distance from the work context. This encompasses everything from instructional settings, tools, workshop exercises, problem-based learning, and real-time mentor guidance, as in apprenticeship on the job. (Collins, Brown, and Newman 1989; Brown, Collins, and Duguid 1991)

Learners can see the value of what they are trying to learn because that value is apparent in the work they are actually doing, and the transfer (of knowledge) conditions and application criteria are likewise relatively salient. (for example, Bransford et al. 1990; Coulson and Feltovich 1993; Lesgold and Nahemow 2005)

Training Must Promote Flexibility and Adaptability

Utilities experts are not just thinking about the systems they control, but they are also thinking about the ways the rest of the work intersects with these. Expertise is not about people forming a rich mental model and holding that in their heads. Rather, it is about gaining an ability to regenerate mental models as needed. We will need to prepare people to think dynamically, probably through scenarios. We will need to prepare people to engage in anticipatory thinking and problem detection.

Training cannot oversimplify. In trying to train for the ability to handle complexity, there have traditionally been two general approaches. The first is to simplify and gradually add in complex elements. Although this seems highly intuitive and may be the most common mode in education and training, for highly complex material it can backfire. Learners can get stuck in the simplifications and petrify there (for example, Feltovich et al. 1989, 2001; Spiro et al. 1989). Another is to address the real complexity, but at the same time make available ample expert and mentoring help. Some of the most outstanding real examples of experience and learning acceleration for highly complex material and tasks have used this latter approach (Bonsangue 1993; Lesgold et al. 1992; Palincsar et al. in press). These programs have used practice problems and materials that were at least as hard as or harder than what the learners were prepared for.

Complexity also involves the fact that the work domain is constantly changing. For workers in areas of engineering and operations, mental models (for example, of the state of the plant) are continually changing as a function of which components are undergoing maintenance, small malfunctions that had not yet been repaired, the changing demands on the plant, and so on (Mumaw et al. 2000). The operators cannot just know the plant. They always have to reconfigure their understanding. They need to mentally simulate how a small malfunction can cascade under the right conditions, for example. Utilities management also must work on a changing playing field.

Training Materials

There is no doubt that distinguishing features of expertise are depth and extent of knowledge. They will continue to be valuable—sometimes critical—to elicit and preserve expert knowledge. Recent Institute for Human and Machine Cognition (IHMC) experience continues to affirm the finding that senior experts possess significant knowledge for designing a process rationale, knowledge that is critical to explaining and in understanding why things are done the way they are done. Invariably in eliciting this knowledge, it is noted that someone with less experience might have made mistakes had they been unaware of this knowledge, sometimes called *tacit knowledge*—unaware because this knowledge is possessed by unique individuals and is undocumented.

Although concept mapping is not the only method for knowledge capture, it is highly efficient for knowledge capture and can be complemented by other methods (Crandall, Klein, and Hoffman 2006). For example, critical decision method procedures can reveal historical rationale and legacy-new interactions, contextualized in stories that would be useful in training. Concept mapping can capture rationale and legacy interactions, as has already been demonstrated in some of the concept maps created at IHMC for various specializations in the utilities.

Knowledge models can be thought of as an attempt to describe what people know. Mental models can be thought of as consisting of a subset of that knowledge that is active in consciousness while one is attempting to understand a current situation. Utilities specializations require an ability to not only form good just-in-time mental models, but also to know when to reject a model on the way to acquiring a better one. Materials for such training can be developed by the critical decision method and the cognitive modeling procedure (see Crandall, Klein, and Hoffman 2005; Klein and Hoffman 2008). The former can result in a corpus of rich case studies representing tough tasks. The latter is a highly efficient method for generating models of practitioner reasoning, making it appropriate for use when mental models are context-dependent, changing, and so on. A corpus of tough cases can be used in unlearning experiences, to reveal knowledge shields and help trainees overcome the dimensions of difficulty.

Critical to any study of expertise acceleration will be a considerable effort to generate a case corpus. Cases will have to be scaled for the stretching of skill. Research has shown that the development of expertise requires practice (for example, Ericsson et al. 2006). And as we have noted, this is not just any kind of practice. The learner must be constantly stretching his or her skill, going beyond the current level of comfortable competence. Included in an effective training program would be a large set of training cases that are scaled for difficulty along the lines of, say, those appropriate for apprentices, journeymen, and different levels of experts. Learning on the job (best accomplished with expert guidance) does afford routine practice, but there needs to be opportunity to stretch (for example, Vygotsky 1978), and everyday job experience may present too much of a hit-or-miss experience of new, unusual things. The ability to practice with tough cases, for any current level of development, can enhance case-based learning/practice, as well as apprentice study on the job.

Training Procedure

Adaptability and Perceptual Learning

To achieve adaptability, training needs to allow for concept-case coupling. Training must involve the learning of conceptual knowledge (that is, regularities, general principles, laws, and so forth). These are the abstractions that apply across cases of application of these principles and, thus, are a vehicle for transfer. But because these are abstractions, such conceptual knowledge must skim across some of the details of a case of application, details that can require the contextual tailoring of the principle for application in some cases or can even render a concept not applicable at all. Real cases of application carry the rich detail of the application environments within them. Training must include considerable opportunity for practicing the application of conceptual knowledge across ranges of cases, for example, through guided apprenticeships or the use of case-based practice technologies (for example, Collins, Brown, and Newman 1992; Lesgold and Nahemow 2005; Spiro et al. 2003).

People learn pretty much what they practice; hence, they should practice in many ways, across many kinds of cases (including ones that involve the same basic principles, but in different kinds of contexts), using many kinds of conceptual tools, points of view, mental organizational structures, investigation and practice strategies, and the like (for example, Spiro et al. 1989). If we want transfer and growth, we need to practice for transfer and growth (Bransford et al. 1979; Spiro et al. 1992). For example, cross-train with others in the organization, those in different work positions, so one can see how the world looks from that vantage point. These ideas hearken those of Schmidt and Björk (1992) and Valkeavaara (1999), in which the authors point out that schemes of learning that are harder in the short run and often even less effective in the short run can yield long-term advantages in both retention and transfer punch.

Also to achieve adaptability, training must support perceptual learning. It is clear that recognition of events or problems as being of a particular and familial type in which the path to solution is also known is a major capability of the expert; this has been termed *recognition-primed decision making* (for example, Klein 1998). It is also clear that these cognitive-perceptual abilities take time to develop and result in new (and effective) ways in which experts view and interpret the world (Chi, Feltovich, and Glaser 1981; Klein and Hoffman 1993). Because this area of development is so crucial to the development of expert performance, it must also be a focus of training for skill improvement (for example, Fadde 2007), and it, like other skills discussed, is probably most amenable to case-based kinds of learning/practice.

Reasoning Skills

Troubleshooting is typically taught as a procedure when it is more appropriate to train it as "a combination of domain and system knowledge (conceptual models of the system including system components and interaction, flow controls, fault states, fault characteristics, symptoms, contextual information and probabilities of occurrence); troubleshooting strategies such as search and replace, serial elimination, and space splitting; and fault testing procedures" (Jonassen 2007, p. 12). Training will have to include an appreciation of the importance of dynamic (or causal reasoning), anticipatory thinking, and problem detection. This focus on transfer stems from the fact that experts, by definition, are able to cope with rare, tough cases and complex, emerging situations. They are flexible and able to adapt to changing and novel circumstances. Training must involve helping people acquire a more powerful toolbox in order to be better able to handle complexity—especially unexpected complexity.

Feedback

Research in expertise studies and naturalistic decision making shows the importance of feedback to the achievement of expertise. Feedback needs to be timely, that is, close in time to the point of decision or action; it also needs to be informative of causal influences, key factors at play, and other meaningful features.

Studies of diverse domains of expertise reveal a great variability between domains (and specializations within domains) in the extent to which workers receive timely, high-quality feedback. In some cases, the inherent nature of the domain makes it impossible for the practitioner to receive prompt feedback (for example, long-term, weather forecasting, intelligence analysis for policy projection). An example finding, from the study of teams, is that teamwork improves following training in which teams are given prompt meaningful feedback about how they coordinate (Salas, Nichols, and Driskell 2007).

cognitive flexibility theory and cognitive transformation theory suggest that an informative kind of feedback, for expertise acceleration, is feedback that helps learners transcend their inclination to invoke a knowledge shield (that is, rationalize away a misunderstanding), and unlearn concepts or notions that incorrectly simplify their understanding of the domain. It is widely believed that people learn more from their mistakes than from what they get right. When everything works the way it is supposed to, one is less likely to receive feedback about what did not work or what might have been done better. Experts seek out corrective feedback, feedback pointing out targets for improvement. It has been said that apprentices make the same mistake twice, journeyman make the same mistake once, and experts work until they never make mistakes. Although this is a point well taken, domain specialists who are intrinsically motivated often seek out corrective feedback that allows them to perceive their errors. Sonnentag (2000) showed that the more experienced problem solvers (domain of software engineering) sought out corrective feedback from coworkers.

Time Compression

We know that training sometimes can lead to accelerated learning. A clear demonstration of this is from the work on intelligent tutoring systems. These rely on a knowledge base of concepts and rules, gleaned from subject matter experts. The computer is provided with or infers information about the learner's level of knowledge and presents problems that are appropriate to that level, and then adds progressive difficulty, specifically for the purpose of pushing the student's understanding to a higher level (Forbus and Feltovich 2001). Tremendous learning gains have been reported with such tutors. The SHERLOCK tutor for electronics troubleshooting reduced four years of on-the-job training to approximately 25 hours of training (Lesgold et al. 1992).

"SHERLOCK presented a concentration of useful cases in a brief period of time. The real world mostly provides opportunities to do the routine. Expertise involving the nonroutine is harder to get from everyday work experience because the right situations occur rarely and often are handled by established experts when they do occur, not by students" (Lesgold 2001, p. 967).

Thus, we know that it is possible to time-compress the experience-feedback cycle. Returning to the notion that it takes years of practice to achieve expertise, we link this to the idea that experts can handle tough cases. Tough cases are rare, by definition, and this may in fact be a reason why it takes so much time to achieve expertise. This line of reasoning directly implies a goal for training: to provide a framework with which a set of tough cases can be used to accelerate the development of expertise. Because of the unique nature of the problem-solving environment in the utilities—that is, system of systems encompassing legacy and modern devices—what could be simulated is a set of scenarios to be used in exercises that vary the root cause of problems. The simulations would involve full details and variations of content, narrative structure, and contextual richness.

The available literature shows that it is possible and sometimes fairly easy to build a curriculum of cases. Experts and managers, working together, are typically successful at identifying the unique and important knowledge areas in which a particular expert excels. Likewise, domain practitioners can readily identify those important concepts in a domain that seem to be especially difficult for others to fully comprehend. Any training program will have a set of concepts deemed especially important to master. There can even be some institutional surveying, investigation to attempt to establish some consensus about what these focal concepts might be (Feltovich, Spiro, and Coulson 1993). First, with regard to content, the scenarios would need to address integrative complexity arising from the interaction of legacy and modern systems. Conceptually, this can be viewed as a set of scenarios where the troubleshooting and diagnosis differentially rely on the interaction of old systems with old systems, new systems with new systems, and new with old systems. Further, these rare cases would be juxtaposed with some routine or typical cases in such a way that the learner can experience the differences that produced the problem and recognize the differences of the diagnostic cues in each.

Given that experts often extrapolate from patterns of cues and think in terms of rich causal models (Linou and Kontogiannis 2004), the simulation scenarios would be set up so that the learners are sometimes led and sometimes misled in their solution seeking. In the case of being misled, the idea is that the simulation purposely misguides them into a common solution, but the reality is that the error is due to a little known issue, such as an interaction between a legacy system and modern devices. Narrative, as the formal apparatus of storytelling, should be used to weave together the sometimes hidden chain of causally related events leading to a particular problem. More formally, narrative determines how the story gets told—that is, who tells the story, the degree of omniscience held, the ordering of the events, and descriptiveness of the setting. For example, with regard to the ordering, an appropriately crafted scenario can manage temporal sequencing to support problem solving. This could juxtapose real-world time with narrative time so that the learners can experience the event through the perspective of the expert (real-world time) and through the more omniscient, third-person perspective of narrative time—that is, presenting events in alternate directions so as to highlight or prominently position certain occurrences for interpretation by the learners. Simulations allow for tremendous flexibility in manipulations of fidelity—differing kinds and amounts of contextual richness. These variations are important because they can emphasize particular elements of the scenario to the learners.

Decision-Making Skills

The decision-making exercise method is an acceleration method developed initially to train high-level decision making skills for military commanders (Klein 2003). A similar method was created by Lia DiBello (2006). The trainer provides information about a critical event, asks the candidate to make a prediction about some unifying variable, shows the actual data, and then continues requesting predictions and providing feedback as the scenario unfolds. The issue is not whether the person can generate an accurate prediction from the start. Rather, the issue is how quickly the person improves. The best people will revise their mental models to improve their predictive accuracy based on what they can learn. In the versions of the method conducted by Klein Associates, trainees in military command were presented scenarios that consisted of a map or diagram plus a one-page description of events thus far, unexpected continuations, and the challenge to forge a decision on the spot. These exercises are intended to be played in groups, with a facilitator, but they can also be played on an individual basis. As the participants walk through the re-creation of a tough-case decision situation, they can be fed information as needed, or as it would unfold in actual situations (but time-compressed). Note that these exercises differ from decision-making games in that there is no one single best or good solution. Rather, the participants must navigate through trade-offs.

Although not having single best answers, exercises can be formed on the model of the simple game. In this form, the decision exercises are easy to play, can be played fairly quickly, are technologically simple, have simple rules, are flexible and adaptable, and are very transportable—they should be capable of being played in a lunchroom or during travel layovers. Each exercise is simple because it focuses on only one or a few particular key concepts, principles, or lessons learned.

If a decision exercise were to be made higher fidelity, it could be thought of as a form of simulation. Simulations at some level of fidelity may be useful in utilities training. Computer-based simulations are increasingly being used to teach abstract or conceptual information (Miller, Lehman, and Koedinger 1999; Resnick 1994; Schank and Farrel 1988). By providing perceptual grounding of abstract concepts, they aid comprehension, and the interactivity can support a deeper understanding of the material (Goldstone and Sakamoto 2003).

Decision exercises, whether the brief form or the simulation, have the following general features:

- A meaningful title
- Background information describing and perhaps explaining the current situation and its origins
- A narrative description of the scenario itself, taking the form of a compelling story that builds to a climax—a dilemma—putting the participants on the “hot seat,” forcing them to make a decision to resolve the situation
- Some sort of visual representation that accompanies the narrative (diagram, map, and so on)
- If meant for team decision making, some sort of role assignments

Team exercises often involve an energetic exchange of opinions. The actual decision is less important than the thinking that goes into it. The decision exercise is a vehicle for triggering the decision-making process and then allowing individuals to reflect on it or discuss it with others.

Exercises can be used to build a familiarity and mutual understanding within a team, so team members know more about how others are likely to react to certain types of situations.

Exercises come from personal experiences, which are described as narratives. Exercises are formed around specific experiences and their context. Exercises are not based on general or typical situations. “We need context in order to exercise our intuition” (Klein 2003, p. 41). For developing instructional cases, domain practitioners are generally able to identify and recall previously encountered tough cases. In addition, managers can often see where staff members repeatedly struggle with some type of judgment or decision. Both the practitioner and the manager can recount personal experiences. From these, one can create a timeline for the described event, and for each key decision in the event, a list of the information requirements of the decision maker. Decision requirements tables serve the dual purpose of formulating a description of the type of dilemma that needs to be practiced, and they can help form the tough cases to be used in decision exercises.

Another benefit of construing a decision exercise as a game is that one can hold tournaments. In a decision-making exercise tournament, multiple teams (each composed of a few to a handful of people, all having different specializations) each craft their own decision exercise and then all of the teams work on the exercises of the others. Then, in a final whole-group discussion, people can compare notes on what was frustrating them and what made exercises challenging for others.

“Several of the participants planned to set up periodic field days during long lunch breaks. They thought that routinely having their colleagues make up and play decision games would be a good chance for cross-functional learning, for making connections, and for building intuitive decision-making skills. Having the decision games center around real issues meant that the decision games were directly relevant to their work and provided a way to make sense of problems that were troubling them. They even decided they could bring the games to upper management to help them articulate their frustrations” (Klein 2003, p. 42).

Klein argues that decision-making exercise can help individuals to the following:

- Broaden and enrich their mental models
- Establish relationships among concepts and cases
- Appreciate the importance of critical cues and patterns
- Fill in the gaps in their experience base
- Learn ways to better handle uncertainty
- Practice at resolving conflicting goals
- Learn to perceive how to spot leverage points—the starting points for constructing new option
- Learn how to detect and anticipate problems
- Understand situations from alternative perspectives
- Practice at allocating limited resources
- Acquire technical knowledge more quickly by putting it in a practical context
- Practice at giving directions or presenting clear statements of assessments or intentions

The tournament may be useful for individual utilities companies but may also be run at the corporate level, if one were to, for example, hold decision exercises for bulk power operations personnel from a number of subsidiary companies. In this case, one thinks of expertise acceleration not in terms of being faster at getting an individual up to expert levels but better at spreading the corporate expertise around—getting the organization as a whole to increase the rate at which it shares its expert knowledge and skill. This tournament notion may be of value to utilities that seek to share and accelerate their expertise for the sake of promoting the industry. In particular, tournaments may be of value in generating a new national-level cohort prepared to launch the next generation of nuclear capabilities.

Teamwork Skills and People Skills

Whereas some utilities specializations rely heavily on perception (for example, perceiving patterns appearing in indicators in a control room), many are not so perceptually based (for example, the activities of the specialist at liaising with a public service commission). Historically, human factors and cognitive engineering have focused on control room operations (for example, human factors analysis following Three-Mile Island). The study of methods of knowledge capture and sharing for the utilities will reach more into domains of management and specializations where people skills are just as, if not more important than, engineering skills. Even in specializations that are reliant on engineering knowledge and skill, people skill is also often equally important, as in the team-leadership skills of the chief district operator (see Section 3).

Many of the previous ideas we have suggested entail training for teamwork and team skills. Time compression can apply to simulated cases involving problem solving by teams and not just individuals. Decision-making exercise and anticipatory training exercises can likewise involve problem solving and discussion by teams and not just individuals.

6
THE WORKING MEETING

Meeting Rationale

The working meeting as an activity emerged in the process of developing this project. To get the right participants to the working meeting, a white paper was written in the context of EPRI's technology innovation efforts, aimed at helping the electric power utilities mitigate the challenges of knowledge loss by developing effective solutions for knowledge capture, transfer, and repurposing. The problems associated with the loss of expert knowledge and skill will only grow in severity under the strains of dramatic labor-force shifts that will see as much as 40–70% of the workforce retiring over the next 5 to 10 years.

As discussed in Section 2, an integral piece of the problem facing the utility business is the following:

> Many technical positions are held by outstanding experts, recognized as having a grasp of their field that far exceeds that of others. These technical positions are often depended upon for mission-critical problem solving prowess or the making of difficult and high-value technical judgments. . . . EPRI's observation of experts in utility domains affirms that it takes a long time to achieve expertise, but also that extraordinary experts who conduct mission-critical activities are recognized as having achieved their extraordinary respect and value after 25 to 35 years of experience. Of course, many people in the utility workforce, including management, currently have 25 to 35 years of experience, but the large proportion of the utility personnel is not recognized as having expertise that vastly exceeds that of others. The large proportion of utility personnel have simply become very good at what they do.

The goals of the working meeting were twofold and symbiotic. The first was for EPRI and the participating scientists to gain a more specific understanding of the idiosyncrasies of utility domains where extraordinary expertise is important. The second was for utility leaders to gain a deeper understanding of possible methods to address the problem. The overarching goal of this meeting of the minds was to create a clear understanding of the research or demonstration projects that must be conducted in order to solve the problem of accelerating the achievement of expertise in the utilities (the research roadmap).

The participants at the working meeting homed in on the following three essential questions:

- What are the defining characteristics of experts and superexperts in the utilities?
- What are the characteristics of the utilities domain that shape the subdomains of expertise, that impact the nature of expertise, and that affect processes of knowledge management?
- What is most likely to work for accelerating the achievement of expertise, and can methods adapted from fields such as expertise studies be effectively deployed in the utilities?

Characteristics of Experts and Superexperts

Sections 2 and 3 delineated some of the characteristics of expertise in the utilities. During the working meeting, the utilities representatives shared a number of stories about experts whom they knew, in specializations that were technical, administrative, and managerial. The vignettes served not only to shape a broader and more grounded understanding of the nature and scope of expertise in the utilities, but also to sharpen the participants' shared understanding of observable, defining features of experts and superexperts.

The utilities representatives noted specific roles and jobs in which expertise is commonly found (including transmission system protection, legacy computer systems operation, and system operation) and roles and jobs where expertise is rarely found (for example, young underground station operators).

Some specific vignettes or capsule views of example experts discussed at the meeting follow. Other examples are documented in the EPRI reports *Pilot Study for Capturing Undocumented Knowledge: Application at the EPRI Nondestructive Examination Center* (1008456) and *Capturing Undocumented Expert Knowledge* (1012127) and EPRI Success Story announcements "PSE&G Captures and Transfers the Knowledge of Power System Experts with EPRI Methodology" (1015217) and "Consolidated Edison Captures Expertise of Retiring Chief District Operator to Preserve Safety and Reliability" (1016118).

Training Officer
This professional started in the business administration ranks and recently rose to the role of Section Manager in Training. This cross-fertilization of domains, as well as personal traits, has led to this professional's development of expertise and the exhibition of potential for superexpertise. This expert has become a sole source of information in the Training Division, specifically training data management. The Training Management System contains the training records of all of the site employees (past and present) as well as all course and instructor information. The data within Training Management System are used to determine the qualifications of each employee, which are in turn used to manage access and tasking. Thus, Training Management System serves a key validating role for the utility, and virtually all other tasking rely on its information. This information system was built in-house by another training and database expert, and then turned over to this expert. Early on, the pair worked together to tweak the system until it suited the needs of the business appropriately. The expert has since managed the system, recording over 10 years of experience with it. Training Management System, for the most part, effectively serves the needs of the organization, and it is the repository of record for training data. As an in-house product, however, robust documentation did not accompany its evolutionary development. This expert has served as the documentation and design proxy to the user community. This expert has engineered and implemented a number of system upgrades, based on feedback by end users. This expert is the main source for educating others on how to use the system, which is particularly important as training processes have changed and forced managers in the field (that is, outside of training) to use the system.

This expert's extensive experience, both with Training Management System and training planning more broadly, is serving to drive change more broadly. The training unit has fundamentally changed the way it does business: it is moving toward scheduling training based on requirements of the job as a first priority. In the past, trainees could get training courses by making the request of their manager. Now, managers have to demonstrate that this training is truly required by linking employees in a capability profile—that is, a profile of each unit and employees capabilities to perform work. This expert has been heading up the capability project, which includes educating managers on capability profiles and drawing on Training Management System to inform training management how training is closing the capability gap. This expert's autodidactic knowledge of the organization's reporting history and the Training Management System system, coupled with a well-developed ability to link seemingly unrelated data together, has allowed her to create and introduce a suite of reports that can pinpoint, to a specific person, where a gap exists, or where training is not required. Although other longtime users of the system have knowledge of Training Management System, no other professional at the utility knows Training Management System, its data, its inherent quirks and workarounds well enough to make the system work to drive change in the manner that this expert is able to do.

In addition to the practical support this expert provides, this expert has long demonstrated an interest in learning for the sake of learning and self-improvement even though the learning is not immediately required for her job. This expert takes every opportunity to create backups to her knowledge, whether that be a reporting tool or another individual. Because of high staff turnover (due to retirements) this expert is taking advantage of her new position and newly hired staff to transfer some of her knowledge on the system and encourage information sharing. Yet, the new staff is on a steep learning curve, so this expert will likely remain the default go-to person for some time to come.

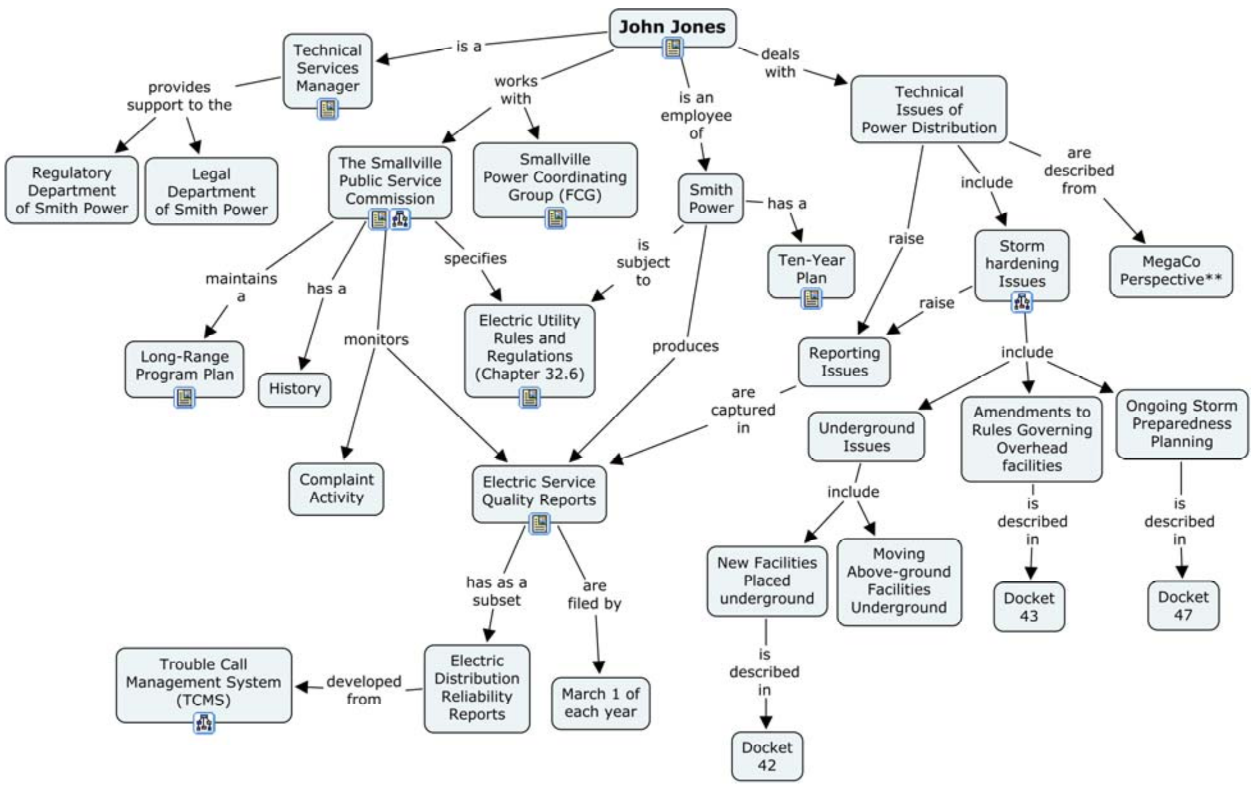
This expert clearly demonstrates the capacity to become a superexpert, and is well-positioned to accelerate the achievement of expertise in others.

Technical Services Manager
The primary responsibilities of this practitioner were supervision of the engineering team that provides distribution technical support for the company, the design and implementation of reliability and power quality initiatives, and representation of company interests in related regulatory matters. He supervises the engineering team that includes power quality engineers, district reliability engineers in the districts, materials and specifications engineers, technology applications engineers, and geographical information systems engineers. Appropriate to his career track, he had an interest in electronics, mechanics, and construction from childhood. While in the employ of the company, he attended classes at community colleges and universities on constructions services, systems operations, controls, human resources management, and other topics. With regard to his extra efforts, he said in a career interview: "I learn on my own—as I need to know I research it and dig out the facts I need to know." His enjoyment of his work was clear: "Four years ago, I started doing Engineering Excellence Training. Specialized training for engineering groups in the districts doing construction projects. Fun and neat to do." Equally obvious was his thirst for learning: "I had to take initiative to learn. Construction foreman would cover the slack for you and expedite the learning process. Lots of hands-on and self-motivation to learn and learn quickly."

He had worked for the company for about 30 years, in jobs including Distribution Engineer, Field Engineer, Construction Services Supervisor, Engineering Division Manager, Power Delivery Manager, Reliability Supervisor, and Technical Services Manager.

As this brief description suggests, he knew the company from top to bottom. He was the go-to guy for all matters related to regulation and liaising with the Public Services Commission.

The concept map below is the top map that integrates concept maps that go into detail concerning his expertise, reasoning, and knowledge. Thus, this concept map overviews his expertise. In developing the concept maps, particular attention was paid to detailing his knowledge of regulatory activities, including knowledge of the Public Services Commission, his strategies for liaising, and his people skills.



Labor Relations Officer
This professional was made an expert by circumstance. As a human resources professional, this expert had been heavily involved in labor relations for 12–15 years. Specifically, this expert had been a member of numerous collective bargaining teams for a decade. This expert was considered by peers as the primary go-to person for arbitration issues. Although this expert did not have a legal background, over time this expert developed a great deal of legal experience and close working relationships with personnel in the legal department. This expert had deep experience in handling many grievances, which were common in this utility's dual union environment where collective bargaining agreements were revised every three years. This experience base enabled this expert to often resolve issues informally, without referral to the

legal department. Moreover, because the utility had not created a database of past arbitrations, this expert became the de facto historian and was often called on to help interpret the spirit of collective agreements and arbitrations.

This expert's broad and deep experience base is at once a tremendous asset and burden to the expert and to the utility. It has resulted in the human resources department becoming something of a one-stop shop for handling issues that otherwise would require cross-department coordination. However, the business processes this expert touches on a daily basis come grinding to a halt in the event of this expert's nonavailability. Moreover, this expert is often burdened by tending to information requests and arbitration support that fall outside daily tasking. Although this expert's skills and knowledge demonstrate the potential for superexpertise, involvement in these key labor issues is a reactive task for this expert, and this expert has not expressed an interest in becoming better at these tasks.

As a one-stop shop, the loss of this expert's knowledge base creates a high likelihood for future instability in the human resources department and beyond. The knowledge holding exhibited in this circumstance is insufficient for the utility. And because the utility makes use of this expert's knowledge base in a reactive mode only, the utility does not know whether this expert could become a superexpert, in this area or any other.

Defining Features of Experts and Superexperts

Much of the discussion at the working meeting hinged on an emerging distinction between experts and superexperts. In the literature on expertise studies, experts are sometimes referred to as *5-percenters*, meant as a reflection of their consistently superior performance. Conceptually, an expert is defined as the following:

> The distinguished or brilliant journeyman, highly regarded by peers, whose judgments are uncommonly accurate and reliable, whose performance shows consummate skill and economy of effort, and who can deal effectively with certain types of rare or tough cases. Also, an expert is one who has special skills or knowledge derived from extensive experience with subdomains.

As the utility representatives relayed the cases, researchers captured defining features of three types of professionals in the utilities, which may be referred to as nonexperts, experts, and superexperts. The notion of a superexpert emerged from the white paper's findings around the concept of an extraordinary expert:

> denote[s] those people who have a capacity exceeding that of others, who are depended upon for mission critical, complex technical guidance or high-stakes decision-making.

Superexperts, then, have demonstrated capacities beyond superior performers in the course of expected and unexpected situations.

This classification helped the working meeting participants focus on a proposed solution set. Participants sought the following: training approaches that might rapidly bring professionals to super-expert status and organizational design elements and procedures that would preserve the knowledge and skills of superexperts.

Nonexperts

Nonexperts were an important discussion point because they are often placed in the unenviable position of taking over for a promoted, transferred, or retired expert. Although the working meeting participants did not question the professionalism of personnel in the utilities, defining features of nonexperts were evident. Nonexperts, who were typically referred to as *junior personnel*, were described as smart but lacking experience, "not yet able to recognize what the work is," "having few or simplified mental models," and lacking a capacity to "respond to common events."

Experts

In contrast, experts in the utilities were described as exhibiting many of the features of experts in other domains that were described in the white paper. The cases included examples in which experts used a wide range of sophisticated mental models to account for flow problems and interacting and interdependent systems, to determine expectancies, to diagnose weird system operations, to describe literal things and situations, and to demonstrate casual relationships. Often, these mental models were employed just-in-time, as in the cases where experts worked to develop design changes and transition new technologies into legacy systems, with all of their foibles. They used tricks of the trade to hasten performance and validate their diagnoses. Experts anticipated situations and knew when to trust their judgment in common and uncommon events. They were sensitive to sociopolitical issues within the organization and knew how to move effectively and efficiently around them. They knew when to justify stepping outside common protocols, often following up these actions by training their bosses on what went wrong and right. They knew the rationales behind critical decisions they and others had made, and they knew when to recapitulate history, often remembering when others cannot what was originally said. They provided consistent responses across seemingly inconsistent situations. And they could effectively scope issues and problems by knowing when to expand their line of view or operations, and when to home in on details.

Another defining feature of experts was their ability to form and work effectively in teams, which are often distributed, ad hoc, short-lived, and reliant upon the sharing of mental models. For all of their skills in teamwork, however, experts were often found to be challenged in mentoring their nonexpert counterparts.

Superexperts

The working meeting participants agreed that superexperts should not be contrasted sharply with experts. Indeed, superexperts are imbued with all of the same characteristics as experts. And yet, as the cases demonstrated, there are features of the performance of superexperts (that is, their knowledge, skills, and presentation) that seem to set them apart from other experts. Working meeting participants identified the following 15 features of superexperts, each of which is observable in aspects of their performance and the reactions of their colleagues:

- Live for the edge. Superexperts recognize that in order to achieve the mission, work needs to be done at the edge of the familiar. Superexperts take satisfaction in opportunities to do work beyond their comfort zone, and examples of their best work often are examples where the work was conducted beyond the edge of the familiar.

- Revel in tough cases. Superexperts recognize the anomalous. Superexperts say, “I’ve never seen this,” and their eyes light up, whereas others may say, “We do not have procedures for this.” Superexperts see tough cases as opportunities to flex and extend their skills.
- Unique incentives. Superexperts certainly expect to be compensated. But typical compensation packages are not the only, or even most important, carrots they seek. Technical achievements (for example, solving the difficult problems and inventing “the thing”) motivate them, whether recognized or not.
- Willingness to improvise. Armed with experience, superexperts know how and when to improvise, when situations go beyond the typical. Whereas experts may have the skills to improvise, superexperts more often demonstrate greater confidence and willingness to do.
- Ad hoc solution provider. Superexperts, by virtue of their continuously demonstrated success, become the go-to pro. Their colleagues use the superexpert’s phone number as a hotline. Rarely do superexperts work for more than half-a-day without receiving a request for help, which they readily respond to, even if the response requires additional effort.
- Rarely say “I do not know.” Superexperts are not comfortable with ignorance. In the rare case in which they find themselves at a loss, superexperts engage in problems solving to make sense of a situation. They do not throw in the towel.
- Rarely say “This is what I believe.” For superexperts, belief is not enough. They are constantly on the hunt for formal, empirical evidence.
- Comprehensive and thorough mental models. Superexperts’ mental models go beyond those of their expert colleagues. When superexperts generate an answer, they not only anticipate consequences throughout a system, but also the collateral consequences to other systems.
- Owners of treasure maps. Superexperts create and use memory artifacts that are unique organizing schemes. These treasure maps reinforce the structure of their knowledge, and they call on them as others would call for manuals.
- Absence causes trauma. For the colleagues who rely on the superexperts, the absence of a superexpert (for example, due to vacations or sick leave) can be a traumatic event. The only circumstance that is more dreadful is to be placed in the role of the superexpert during the superexpert’s absence.
- Can see perspectives of others. Unlike the expert who becomes engrossed in the problem at hand, superexperts have the ability to also consider the perspectives of others involved in the situation. Superexperts understand (even to the point of sympathy) that other people simply cannot think the way they do, and that others have to discover on their own things that the superexpert already knows or immediately discerns. Superexperts display great patience with others, helping them gain understanding from their own perspective, mentoring those who are developing their own expertise.
- Lead, but often only by example. Superexperts have the admiration of their peers and subordinates and develop knacks for employing their special position in furtherance of the mission. Others follow them in order to learn and get their help. But superexperts do not spend much of their time explicitly developing leadership qualities. Although they may find themselves in management roles, they are not always comfortable there.

- Continuous learning. Superexperts thirst for knowledge. They self-select into learning opportunities, both formal and informal. They are students of their craft, and they practice with zeal. They fear getting stale in their domain of expertise. They are among the first to sign up for training events, and the last to leave, staying behind to ask the instructors for clarifications. They view all of life as an opportunity for development and often bring seemingly unrelated activities and knowledge to bear in the workplace.
- Learning from mistakes. Journeymen and experts learn from their mistakes. Superexperts learn until they do not make mistakes. Yet, superexperts retain a remarkably vivid recall of errors. Whereas others may wish to forget about their last fault, superexperts think about their past mistakes, which both gall and intrigue them. They revisit their performance, searching for ways they were tripped up and considering what they could have done differently.
- Knowledge and skills may not be *write-downable*. Because their experience is vast, superexperts' mental models so comprehensive, and their perceptual and motor skills so tightly interwoven, it may be very difficult to completely capture the knowledge and skills of the superexpert.

Organizational Context

Within the utilities, the acceleration of expertise is the purview of human resources and human capital departments. The utilities representatives at the working meeting brought extensive experience in human resources and a keen interest in the development of expertise. They observed that utilities human resources departments are doing exceptionally well at developing leadership through effective succession planning, the creation of effective retention programs through workforce planning, effective training in procedures and workplace issues, effective human resources information technology systems, and meaningful performance measurement approaches and methods.

However, expertise is developed by mostly passive means. Utilities tend to rely on the accrual of experience, or select individuals for already identified experts to mentor. These approaches require not only a great deal of time, but also specific valid selection criteria for identifying potential experts. To be successful, individuals will also require skill sets that many experts might not possess (for example, the ability to effectively mentor) and processes that many organizations may not institutionalize (for example, the recording and use of timely, direct feedback on performance).

Career development programs also do not favor the development of expertise, particularly technical expertise. There are very few incentives that encourage the development of technical expertise. *Wizard* and *guru* are not necessarily signs of a rewarded status. And for many experts in the utilities, as in the computer and nuclear industries, the primary incentives that comprise many career development programs (for example, money) are not incentives that drive their self-development. Experts and superexperts, as we have pointed out, are motivated by the thrill of victory in solving problems or providing effective support to their teammates. Regrettably, improvisation may not only lack reward, but it can also be punished.

Another challenge in career development stems from the fact that organizational and business cultures tend to track the development of role-specific skill and expertise into the tracks of leadership roles. Leadership roles tend to be filled by professionals with prior experience in military organizations, where leadership is actively fostered. But experts—particularly technical experts—may have very little interest in leadership positions. This situation presents something of a "catch-22" for the utilities, as technical expertise can be quite useful in roles typically performed by corporate leaders, such as negotiation.

The final challenge organizations face lies in being attuned to the extent of the mission impact of experts, particularly superexperts. Although many organizations know that they rely on experts to achieve their mission, they often do not realize the degree of dependence until those experts leave, often through retirement that is encouraged by human resources policies. Hoffman and Hanes (2003) referred to this as the *panic attack mode*.

Turning to training and learning, the utilities representatives reported that most, if not all, utilities want to create organizations of continuous learning, and to be more explicit about the achievement of expertise as a corporate goal. Attaining the goal, however, can be challenged by, among other things, the need to accomplish the immediate mission, individual abilities to teach/mentor and learn/apprentice, and labor and organizational stovepipes. Although the first challenge will never go away and must always be considered, the second challenge can be mitigated with effective strategies. The meeting touched only sparingly on the third issue, but all agreed on its fundamentality for the overarching goal. Without corporate "teeth," acceleration will likely never happen.

Knowledge Loss Risk Assessment

Within these challenging contexts, the utilities are pursuing strategies to assess the risks of lost knowledge.

Current efforts are focused on identifying experts, and these will certainly have value for the utilities. One successful approach has been put forth by the Tennessee Valley Authority. This quantitative approach to knowledge loss risk assessment "is designed to identify positions and people where the potential knowledge loss is greatest and most imminent" (IAEA 2006), and it includes ratings based on two factors: time until retirement (attrition risk factor) and position criticality (position risk factor). The factors can be rated on a scale of 1 to 5. For the attrition risk factor, the scale runs from 1 = Projected Retirement Date Within or Greater than Sixth Fiscal Year to 5 = Projected Retirement Date Within Current or Next Fiscal Year. The position risk factor scale runs from 1 = Common Knowledge and Skills (where external hires possessing the knowledge/skill are readily available and require little additional training) to 5 = Critical and Unique Knowledge and Skills (specifically, mission-critical knowledge/skills with the potential for significant reliability or safety impacts, and/or site-specific knowledge, and/or knowledge undocumented, and/or requires 3–5 years of training and experience, and/or no ready replacements available). Multiplying the factors results in a total risk factor, which can be applied to every position or person on staff. A total risk factor of 20–25 should be considered a "High priority. Immediate action needed. Specific replacement action plans with due dates will be developed to include: method of replacement, knowledge management assessment, specific training required, on-the-job training/shadowing with incumbent" (IAEA).

Approaches for capturing and transferring expertise have been delineated through a series of reports published by EPRI. From providing guidance for elicitor-led knowledge capture (EPRI 1002896) to innovative methods for self-elicitation and automated knowledge capture (EPRI 1009581), EPRI has advanced the utility industry toward reliable methods for mitigating knowledge loss.

Less concerted, however, is the effort spent on identifying potential experts and superexperts. Utility representatives at the working meeting noted that some professionals self-identify themselves as experts. Yet true experts tend to underpredict their performance and do not call themselves out as such. Thus, the identification issue is challenged by an illusion of understanding put forward by nonexperts. Not identifying potential can only multiply the risk of losing expertise.

7 ROADMAP FOR ACCELERATING THE ACHIEVEMENT OF EXPERTISE

With a common view of the nature and scope of expertise, the working meeting participants generated a set of research strategies for enabling the utilities to accelerate the achievement of expertise. The strategies build upon the suggestions offered in Section 5 and were confirmed by the participants as a useful direction.

The strategies were organized with regard to their focus: trials and demonstrations, field research topics, and training and learning. They were also prioritized with regard to the timeframes of their successful deployment. The timeframes are near-term (1 to 3 months), medium-term (1 to 12 months), and long-term (6 to 24 months). The working meeting participants recognized that none of the strategies will work in isolation and that a combination of approaches, conducted in parallel, would be the best strategy to ensure the demonstration of a robust method for expertise acceleration.

Trials and Demonstrations

Additional trials and demonstrations are needed to further define the nature of the problem of accelerating expertise.

Development of a Corpus of Case Studies of Superexperts and Experts in Action (Near-Term)

The cases of expertise discussed at the working meeting helped the participants delineate the nature and scope of expertise. Accompanied by a statement of the problem, additional case studies would draw attention to the urgency of expertise loss and may generate sufficient interest from the utilities to craft a longer term program to mitigate the loss. The collection of case studies could be facilitated by development of a community of practice among knowledge elicitation practitioners.

Survey of Utilities Managers to Overview Knowledge Management and Loss of Expertise (Near-Term)

Utilities managers are in the vanguard of knowledge management and expertise loss. They have the frontline view of the role of expertise in their organizations and have a refined sense of what its loss might mean. Their decisions impact the level and nature of knowledge management efforts to protect against losses, and ensure that knowledge moves efficiently and effectively across their charges. A broadcast survey focusing on these issues would be the best method to understand the state of the expertise in the utilities, especially the striation into experts and superexperts.

Surveying Selection Methods of Potential Superexperts (Medium-Term)

A key piece to any program geared toward acceleration will be the selection of potential experts and superexperts. Acceleration efforts must be targeted toward promising professionals or risk time and money ill-spent. Selection, as our participants demonstrated, is not a straightforward proposition. Methods such as the 5 × 5 provide managers tools with which to consider the risk of losing expertise, but they do not help identify nascent expertise. Better understanding how managers are trying to make such selections could be one aspect of the survey. Selection methods stemming from the 15 characteristics of superexperts could also be devised and tested in a pilot study. Such a study would best be implemented through a longitudinal method involving observation of workplaces and iteration of the 15 characteristics.

Field Research

Field research topics are near- to long-term strategies geared toward a robust delineation of the nature of expertise in the utilities. The strategies have been successfully deployed in hundreds of domains, and to some extent in the utilities. These previous efforts would provide the researchers a springboard from which to deploy. The suggested items that follow are methods that could be applied right now to attempt to accelerate the achievement of expertise, and research topics that should be pursued to measure their effectiveness and seek synergies that would be achievable in real-world situations. As methods, they are individually well-understood in isolated, lab-like situations. As research topics, they are activities that researchers should be brought into, in real time, so that the synergies can be sought by those who would seek them. The barrier that needs to be overcome is that people in industry who need to apply these methods simply want to make some problem go away—they are not interested directly in the theoretical or long-term benefit of the larger research problem.

Cognitive Task Analysis (Near-Term)

Identified experts and superexperts would participate in methods designed to capture their knowledge, reasoning, and skills. Findings on knowledge capture in fields of expertise studies, including studies in the utilities, demonstrate the value of certain cognitive task analysis procedures, specifically concept mapping and the critical decision method. Cognitive task analysis is the cornerstone strategy from which several others spring. It will bring into high relief, through extensive detail, the nature of tough cases in the utilities.

Each could provide unique and complementary accelerators.

Continue Knowledge Capture from Superexperts (Near-Term)

As workforce diversity expands and some skills become rare, there arises a need to identify and capture the standard knowledge that enables everyday mission accomplishment. Critical chunks of this knowledge, held by experts, often go undocumented. As legacy systems meet with technology advances, uncommon wisdom, gathered in the superexpert, becomes a key enabler. In most cases, this wisdom is undocumented.

Gathering and Cataloging Tough Cases (Medium-Term)

A particular method for accelerating the achievement of expertise derives directly from the unique ability of experts to cope with rare and tough cases. The acceleration method is called *tough case time compression*. A reason it takes so long to achieve expertise is that tough cases are rare. Thus, if a large corpus of rare tough cases could be developed, it could be used as training materials.

Selection Research (Based upon Surveying Selection Methods) (Long-Term)

Cognitive task analysis also provides empirical data to inform further research on selection criteria and methods. By providing deep insight to the skills and knowledge at work in the utilities, cognitive task analysis data could be used to refine criteria and methods currently used. Competency models, a combination of identified skills, knowledge, and attributes required for achievement of expertise and superexpertise, could be developed, enabling active selection of potential candidates for acceleration, an improvement over the current passive approaches.

Sharpen Feedback Given to Prospective Experts (Near-Term)

Timely, direct, and critical feedback is a key feature in the development of expertise. The utilities representatives cited annual performance reviews as the core tool utilities organizations used to provide feedback. Although perhaps useful for documenting career progression, performance reviews cannot provide the insight necessary to drive the achievement of expertise. This strategy, then, is about implementing organizational processes geared toward critiquing performance for the purpose of achieving what superexperts do when they languish over their mistakes.

After-Action Reviews

After-action reviews, if run by a skilled facilitator, are one approach and can provide a shared understanding of how a team handled challenging incidents. Information technologies may also be useful here, as they are in the aviation community's Aviation Safety Reporting System. Both methods could prove useful in developing a deep understanding of the organization's resilience and how it can be maintained.

Pre-Mortem

A relatively simple technique to implement, the pre-mortem is the hypothetical opposite of a postmortem. A postmortem in a medical setting allows health professionals and the family to learn what caused a patient's death. Everyone benefits except, of course, the patient. A pre-mortem in a business setting comes at the beginning of a project rather than at the end, so that the project can be improved rather than autopsied. Unlike a typical critiquing session, in which project team members are asked what might go wrong, the pre-mortem operates on the assumption that the patient has died, and so asks what did go wrong. The team members' task is to generate plausible reasons for the project's failure. Although many project teams engage in pre-launch risk analysis, the pre-mortem's prospective hindsight approach offers benefits that other methods do not. Indeed, the pre-mortem does not just help teams identify potential problems early on. It also reduces the kind of "damn-the-torpedoes" attitude often assumed by people who are overinvested in a project. Moreover, in describing weaknesses that no one else has mentioned, team members feel valued for their intelligence and experience, and others learn from them. The exercise also sensitizes the team to pick up early signs of trouble once the project gets underway.

Training and Learning

Training and learning are medium- to long-term strategies that transfer the empirical insights of trials and demonstrations and field research topics into sustainable features of continuous learning organizations.

Assess Barriers to Learning (Long-Term)

The utilities representatives provided some insight into the barriers to learning within the utilities. The problem, however, must be fully understood if programs for acceleration are to succeed. This strategy would be slated for the long-term, and would accompany others. Early efforts would involve a direct assessment through cognitive task analysis findings of the barriers, which could then be tracked and continuously cataloged as other strategies were enacted.

On-the-Job Training (Medium-Term)

On-the-job training is the first, and often only, strategy corporations rely on for learning—indeed, as much as 60% of all training is on-the-job training. New performers shadow experienced performers, learning how to accomplish tasks as they are assigned to them. Invariably, a great deal of learning opportunities is missed, as the critical mission or turnover interjects. More problematic, mentors and mentees typically lack the abilities to support knowledge transfer. Although some *train-the-trainer* programs may provide guidance, it is usually overly procedural and does not address best methods for transferring the cognitive elements of performance. This strategy would focus on developing on-the-job training programs in the utilities, specifically by training experts and superexperts how to best train their apprentices, and helping the apprentices learn how best to learn.

Conclusion

We believe that the ideas and cases discussed at the working meeting have provided a refined view of an approach to knowledge management in general, and expertise acceleration in particular. The roadmap specifies a number of actionable recommendations to take these ideas, and those of the initial white paper, toward one or more demonstration projects. These projects will have the following benefits:

- Surveys will bring issues of workforce and knowledge loss into focus at high levels of management and leadership within the utilities. They will move discussion of the problem into an even finer grain of detail than current knowledge loss risk assessment approaches. Broad recognition of the problems and challenges will motivate continuing efforts to create a knowledge culture.

- Field studies and cognitive task analysis will commence a process of knowledge capture, revealing the knowledge, skills, and strategies of utilities experts, so that this expertise might subsequently be used in training.
- At the same time, field studies and cognitive task analysis will generate materials that can be used in attempts to accelerate the achievement of expertise, including tough case time compression and decision-making exercises.

The issue of accelerated learning is by no means restricted to the concerns of the utilities. A similar concern, also linked to workforce and expertise loss issues, exists in the government and the military. Indeed, entire Department of Defense programs are aimed at issues of accelerated training across the proficiency scale. The ideas presented here represent the only concerted attempt to focus specifically on accelerating the achievement of expertise and superexpertise. Thus, the proposed efforts have significant implications for expertise studies, broadly, and the applications of sciences of instructional design. Thus, the proposed efforts could have a far-reaching impact.

It takes upwards of 10 years to achieve expertise and an investment of hundreds of thousands of dollars in training and salaries. Any years that might be shaved off of that would represent a significant savings, and a significant lessening of the organization's risk if critical expertise were lost. One utility estimated that transferring their experts' knowledge to other engineers saves $100,000 per year on customers out of service, relative to their baseline failure rate. Anything that can be done to elicit, preserve, and share expert knowledge skills and reasoning is indubitably a significant insurance policy for organizations that depend critically on undocumented, significant expertise.

A
REFERENCES

Adelman, L. (1989). “Management issues in knowledge elicitation.” *IEEE Transactions on Systems, Man and Cybernetics*, 19, 483–488.

Alee, V. (1997). *The knowledge evolution: Expanding organizational intelligence.* Boston: Butterworth-Heinemann.

Anderson, R. C. and Pichert, J. W. (1978). “Recall of previously unrecallable information following a shift of perspective.” *Journal of Verbal Learning and Verbal Behavior*, 17, 1–12.

Ausubel, D. P., Novak, J. D., and Hanesian, H. (1978). *Educational psychology: A cognitive view,* 2nd ed. New York: Holt, Rinehart and Winston.

Baddeley, A. D. and Longman, D. J. A. (1978). “The influence of length and frequency of training on the rate of learning to type.” *Ergonomics*, 21, 627–635.

Ballas, J. A. (2007). “Human centered computing for tactical weather forecasting: An example of the ‘“Moving Target Rule.’” In R. R. Hoffman (Ed.), *Expertise out of context* (316–326). Mahwah, NJ: Lawrence Erlbaum Associates.

Banaji, M. R. and Crowder, R. G. (1989). “The bankruptcy of everyday memory.” *American Psychologist*, 44, 1185–1193.

Barber, P. (1988). *Applied cognitive psychology*. London: Methuen.

Barrett, R., Kandogan, E., Maglio, P. P., Haber, E. M., Takayama, L. A., and Prabaker, M. (2004). “Field studies of computer system administrators: Analysis of system management tools and practices.” *Proceedings of Computer Supported Cooperative Work*. [Based on ital in following entry]

Becerra-Fernandez, I. and Aha, D. W. (1999). “Case-based problem solving for knowledge management systems.” In *Proceedings of the Twelfth International Florida AI Research Society Conference* (219–223). Menlo Park, CA: AAAI Press.

Becerra-Fernandez, I., Gonzalez, A., and Sabherwal, R. (2004). *Knowledge management: Challenges, solutions, and technologies.* Upper Saddle River, NJ: Prentice-Hall.

Becerra-Fernandez, I. and Leidner, D. (Eds.) (2008). *Knowledge management: An evolutionary view.* Upper Saddle River, NJ: Prentice-Hall.

Berkman, E. (2001, April). “When bad things happen to good ideas.,” Darwin. [http://www.darwinmag.com/read/040101/badthings.html Downloaded 25 June 2005.]

Berry, D. C. and Broadbent, D. E. (1984). “On the relationship between task performance and associated verbalizable knowledge.” *Quarterly Journal of Experimental Psychology*, 36A, 209–231.

Besnard, D. and Bastien-Toniazzo, M. (1999). "Expert error in trouble-shooting: An exploratory study in electronics." *International Journal of Human-Computer Studies*, 50, 391–405.

Bonaceto, C. and Burns, K. (in press). "Mapping the mountains: A survey of cognitive engineering methods and uses." In R. R. Hoffman (Ed.), *Expertise out of context: Proceedings of the Sixth International Conference on Naturalistic Decision Making.* Mahwah, NJ: Lawrence Erlbaum Associates.

Bonsangue, M. V. (1993). "Long-term effects of the Calculus Workshop Model." *Cooperative Learning*, 13(3), 19–20.

Book, W. F. (1908). "The psychology of skill with special reference to its acquisition in typewriting." *University of Montana Studies in Psychology, vol. 1.* Missoula, MT: University of Montana Press.

Book, W. F. (1924). "Voluntary motor ability of the world's champion typists." *Journal of Applied Psychology*, 8, 283–308.

Boy, G. (1998). *Cognitive function analysis.* Stamford, CN: Ablex.

Bramer, M. (Ed.) (1985). *Research and development in expert systems.* Cambridge: Cambridge University Press.

Bransford, J. D. and Franks, J. J. (1976). "Toward a framework for understanding learning." In G. H. Bower (Ed.), *The psychology of learning and motivation*. New York: Academic Press.

Bransford, J. D., Franks, J. J., Morris, C. D., and Stein, B. S. (1979). "Some general constraints on learning and memory research." In L. S. Cermack and F. I. M. Craik (Eds.), *Levels of processing in human memory* (331–354). Hillsdale, NJ: Lawrence Erlbaum Associates.

Bransford, J. D., Sherwood, R. S., Hasselbring, T. S., and Kinzer, C. K. (1990). "Anchored instruction: Why we need it and how technology can help." In D. Nix and R. Spiro (Eds.), *Cognition, education, and multimedia*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Brooking, A. (1999). *Corporate memory: Strategies for knowledge management*. London: Thomson.

Brule, J. F. and Blount, A. (1989). *Knowledge acquisition*. New York: McGraw-Hill.

Bryan, W. L. and Harter, N. (1897). "Studies in the physiology and psychology of the telegraphic language." *Psychological Review*, 4, 27–53.

Burns, C. and Hajdukiewicz, J. R. (2004). *Ecological interface design*. Boca Raton, FL: CRC Press.

Burns, C. M., Bryant, D., and Chalmers, B. (2001). "Scenario mapping with work domain analysis." In *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting* (424–428). Santa Monica, CA: Human Factors and Ergonomics Society.

Cañas, A. J., Hill, G., Carff, R., Suri, N., Lott, J., Eskridge, T., Gómez, G., Arroyo, M., and Carvajal, R. (2004). “CmapTools: A knowledge modeling and sharing environment.” In A. J. Cañas, J. D. Novak, and F. M. González (Eds.), *Concept Maps: Theory, Methodology, Technology, Proceedings of the 1st International Conference on Concept Mapping* (125–133). Pamplona, Spain: Universidad Pública de Navarra.

Capturing and Using High-Value Undocumented Knowledge in the Nuclear Industry—Guidelines and Methods. EPRI, Palo Alto, CA: 2002. 1002896.

Capturing Undocumented Expert Knowledge. EPRI, Palo Alto, CA: 2005. 1012127.

Chase, W. G. and Simon, H. A. (1973). “Perception in chess.” *Cognitive Psychology*, 4, 55–81.

Chi, M., Feltovich, P., and Glaser, R. (1981). “Categorization and representation of physics problems by experts and novices.” *Cognitive Science*, 5(2), 121–152.

Chi, M. T. H., Glaser, R., and Farr, M. L. (Eds.) (1988). *The nature of expertise*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Chow, R. and Vicente, K. J. (2002). “A field study of emergency ambulance dispatching: Implications for decision support.” In *Proceedings of the Human Factors and Ergonomics Society 46th Annual Meeting* (313–317). Santa Monica, CA: Human Factors and Ergonomics Society.

Clancey, W. J. (1993). “The knowledge level reinterpreted: Modeling socio-technical systems.” In K. M. Ford and J. M. Bradshaw (Eds.), *Knowledge acquisition as modeling* (33–49, Pt. 1). New York: Wiley.

Collins, A., Brown, J. S., and Newman, S. E. (1989). “Cognitive apprenticeship: Teaching the craft of reading, writing and mathematics.” In L. B. Resnick (Ed.), *Knowing, learning and instruction: Essays in honor of Robert Glaser* (453–494). Hillsdale, NJ: Lawrence Erlbaum Associates.

Committee on Science, Engineering, and Public Policy. (2006). *Rising above the gathering storm: Energizing and employing America for a brighter economic future*. Washington, DC: National Academies Press.

Cooke, N. M. and McDonald, J. E. (1987). “The application of psychological scaling techniques to knowledge elicitation for knowledge-based systems.” *International Journal of Man-Machine Studies*, 26, 533–550.

Corbett, A. T. (2001). “Cognitive computer tutors: Solving the two-sigma problem.” In *User modeling: Proceedings of the Eighth International Conference* (137–147). Berlin: Springer-Verlag.

Coulson, R.L. and Feltovich, P.J. (1993). “Problem-based student-directed learning in medicine.” *American Podiatric Medical Association*, 83, 319–327.

Coulson, R. L., Feltovich, P. J., and Spiro, R. J. (1989). "Foundations of a misunderstanding of the ultrastructural basis of myocardial failure: A reciprocation network of oversimplifications." *Journal of Medicine and Philosophy* (Special issue on The Structure of Clinical Knowledge), 14, 109–146.

Coulson, R. L., Feltovich, P. J., and Spiro, R. L. (1997). "Cognitive flexibility in medicine: An application to the recognition and understanding of hypertension." *Advances in Health Sciences Education*, 2, 141–161.

Craik, F. I. M. and Tulving, E. (1975). "Depth of processing and the retention of words in episodic memory." *Journal of Experimental Psychology: General*, 104, 268–294.

Crandall, B., Klein, G., and Hoffman, R. R. (2006). *Working minds: A practitioner's guide to cognitive task analysis*. Cambridge, MA: MIT Press.

Cullen, J. and Bryman, A. (1988). "The knowledge acquisition bottleneck: Time for reassessment?" *Expert Systems*, 5, 216–225.

Davenport, T. H. and Prusak, L. (1998). *Working knowledge: How organizations manage what they know.* Cambridge, MA: Harvard Business School Press.

David, J.-M., Krivine, J.-P., and Simmons, R. (Eds.) (1993). *Second-generation expert systems*. Berlin: Springer-Verlag.

Dawson-Saunders, B., Feltovich, P. J., Coulson, R. L., and Steward, D. E. (1990). "A survey of medical school teachers to identify basic biomedical concepts medical students should understand." *Academic Medicine*, 65, 448–454.

De Keyser, V., Decortis, F., and Van Daele, A. (1998). "The approach of Francophone ergonomy: Studying new technologies." In V. De Keyser, T. Qvale, and B. Wilpert (Eds.), *The meaning of work and technological options* (147–163). Chichester, England: Wiley.

Dekker, S. W. A., Nyce, J. M., and Hoffman, R. R. (March-April 2003). "From contextual inquiry to designable futures: What do we need to get there?" *IEEE Intelligent Systems,* 74–77.

Dewey, J. (1916). *Democracy and education*. New York: Macmillan.

Diderot, D. (with d'Alembert, J. D.) (Eds.) (1751–1772). Encyclopédie ou Dictionnaire raisonné des sciences, des arts et des métiers, par une Société de Gens de lettere. Paris: Le Breton. Compact Edition published in 1969 by The Readex Microprint Corporation, New York. Translations of selected articles can be found at http://www.hti.umich.edu/d/did/

Dodds, P. and Fletcher, J. D. (2004). "Opportunities for new '"smart'" learning environments enabled by next generation web capabilities." *Journal of Educational Multimedia and Hypermedia*, 13, 391–404.

Duda, J., Gaschnig, J., and Hart, P. (1979). "Model design in the PROSPECTOR consultant system for mineral exploration." In D. Michie (Ed.), *Expert systems in the micro-electronic age* (153–167). Edinburgh: Edinburgh University Press.

Ebbinghaus, H. (1885). *On memory: A contribution to experimental psychology*. (H. Ruger and C. Busenius, Trans.). New York: Teacher's College, Columbia University.

Elstein, A. S., Shulman, L. S., and Sprafka, S. A. (1978). *Medical problem solving*. Cambridge, MA: Harvard University Press.

Endsdley, M. R. and Garland, D. L. (2000). *Situation awareness analysis and measurement*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Ericsson, K. A. (2006). "The influence of experience and deliberate practice on the development of superior expert performance." In K. A. Ericsson, N. Charness, P. J. Feltovich, and R. R. Hoffmann (Eds.), *The Cambridge handbook on expertise and expert performance*. Cambridge, UK: Cambridge University Press.

Ericsson, K. A., Charness, N., Feltovich, P. J., and Hoffmann, R. R. (2006). *The Cambridge handbook on expertise and expert performance*. Cambridge, UK: Cambridge University Press.

Ericsson, K. A. and Simon, H. A. (1993). *Protocol analysis: Verbal reports as data (2nd. ed.).* Cambridge, MA: MIT Press.

Evans, A.W., Jentsch, F., Hitt, J. M., Bowers, C., and Salas, E. (2001). "Mental model assessments: Is there a convergence among different methods?" In *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting* (293–296). Santa Monica, CA: Human Factors and Ergonomics Society.

Fadde, J. F. (2007). *Instructional design for advanced learners: Training recognition skills to hasten expertise.* Educational Technology Research & Development.

Feigenbaum, E. A., Buchanan, B. G., and Lederberg, J. (1971). "On generality and problem solving: A case study using the DENDRAL program." In B. Meltzer and D. Michie (Eds.), *Machine intelligence* 6 (165–190). Edinburgh: Edinburgh University Press.

Feltovich, P. J. and Barrows, H. S. (1984). "Issues of generality in medical problem solving." In H. G. Schmidt and M. L. DeVolder (Eds.), *Tutorials in problem-based learning* (128–142). Assen, the Netherlands: Van Gorcum.

Feltovich, P. J., Coulson, R. L., and Spiro, R. J. (2001). "Learners' (mis)understanding of important and difficult concepts: A challenge to smart machines in education." In K. D. Forbus and P. J. Feltovich (Eds.), *Smart machines in education* (349–375). Menlo Park, CA: AAAI/MIT Press.

Feltovich, P. J., Hoffman, R. R., Woods, D., and Roesler, A. (May-June 2004). "Keeping it too simple: How the reductive tendency affects cognitive engineering." *IEEE Intelligent Systems*, 90–94.

Feltovich, P., Spiro, R., and Coulson, R. (1989). "The nature of conceptual understanding in biomedicine: The deep structure of complex ideas and the development of misconceptions." In D. Evans and V. Patel (Eds.), *Cognitive science in medicine: Biomedical modeling.* Cambridge, MA: MIT Press.

Feltovich, P. J., Spiro, R. J., and Coulson, R. L. (1993). "Learning, teaching and testing for complex conceptual understanding." In N. Frederiksen, R. Mislevy, and I. Bejar (Eds.), *Test theory for a new generation of tests* (181–217). Hillsdale, NJ: LawrenceErlbaum Associates.

Fiore, S. M. and Salas, E. (Eds.) (2008). "Cognition, competition, and coordination: Understanding expertise in sports and its relevance to learning and performance in the military." Special Issue of *Military Psychology*, in press.

Fisher, A. (March 21, 2005). "How to battle the coming brain drain." *Forbes*, 121–131.

Flin, R., Salas, E., Strub, M., and Martin, L. (Eds.) (1997). *Decision making under stress: Emerging themes and applications*. Aldershot, UK: Ashgate.

Forbus, K. D. and Feltovich, P. J. (Eds.) (2001). *Smart machines in education*. Menlo Park, CA: AAAI Press.

Ford, K. M. and Adams-Webber, J. R. (1992). "Knowledge acquisition and constructive epistemology." In R. Hoffman (Ed.), *The cognition of experts: Psychological research and empirical AI* (121–136). New York: Springer-Verlag.

Ford, K. M., Coffey, J. W., Cañas, A., Andrews, E. J., and Turne, C. W. (1996). "Diagnosis and explanation by a nuclear cardiology expert system." *International Journal of Expert Systems*, 9, 499–506.

Forsyth, D. E. and Buchanan, B. G. (1989). "Knowledge acquisition for expert systems: Some pitfalls and suggestions." *IEEE Transactions on Systems, Man, and Cybernetics*, 19, 345–442.

Funke, J. and Frensch, P. A. (2007). "Complex problem solving: The European perspective." In D. H. Jonassen (Ed.), *Learning to solve complex scientific problems* (25–47). New York: Lawrence Erlbaum Associates.

Gaines, B. (2003). "Organizational knowledge acquisition." In C. W. Holsapple (Ed.), *Handbook of knowledge management, vol. 1* (317–347). Berlin: Springer-Verlag.

Gagné, R. M. and Smith, E. C. (1962). "A study of the effects of verbalization on problem solving." *Journal of Experimental Psychology*, 63, 12–18.

Gaines, B. R. and Boose, J. H. (Eds.) (1988). *Knowledge acquisition tools for expert systems*. London: Academic Press.

Gentner, D. and Stevens, A. L. (Eds.) (1983). *Mental models*. Mahwah, NJ: Lawrence Erlbaum Associates.

Gilbreth, L. M. (1934). "Time and motion study techniques." *Occupations*, 12, 35–38.

Glaser, R. (1987). "Thoughts on expertise." In C. Schooler and W. Schaie (Eds.), *Cognitive functioning and social structure over the life course* (81–94). Norwood, NJ: Ablex.

Glaser, R., Lesgold, A., Lajoie, S., Eastman, R., Greenberg, L., Logan, D., Magone, M., Weiner, A., Wolf, R., and Yengo, L. (1985). "Cognitive task analysis to enhance technical skills training and assessment." Report, Learning Research and Development Center, University of Pittsburgh, Pittsburgh, PA.

Goffee, R. and Jones, G. (March 2007). “Managing clever people.” *Harvard Business Review*.

Goldstone, R. L. and Sakamoto, Y. (2003). “The transfer of abstract principles governing complex adaptive systems.” *Cognitive Psychology*, 46, 414–466.

Gordon, S. E. (1992). “Implications of cognitive theory for knowledge acquisition.” In R. R. Hoffman (Ed.), *The psychology of expertise: Cognitive research and empirical AI* (99–120). Mahwah, NJ: Lawrence Erlbaum Associates.

Gordon, S. E. and Gill, R. T. (1997). “Cognitive task analysis.” In C. Zsambok and G. Klein (Eds.), *Naturalistic decision making* (131–140). Mahwah, NJ: Lawrence Erlbaum Associates.

Gross, M., Hanes, L., and Ayres, T. (2002). “Capturing undocumented worker-job-knowledge at electric utilities: The EPRI Strategic Project.” In *Proceedings of the IEEE 7th Conference on Human Factors and Power Plants* (6.20–6.24), New York: IEEE.

Haber, E. (2005). “Sense making Sysadmins: Lessons from the Field.” Paper presented at the Sense making Workshop at the Computer-Human Interaction Conference, Association for Computing Machinery.

Hanes, L. F. and Gross, M. M. (2002). “Capturing valuable undocumented knowledge: Lessons learned at electric utility sites.” In *Proceedings of the IEEE 7th Conference on Human Factors and Power Plants* (6.25–6.29), New York: IEEE.

Hart, A. (1986). *Knowledge acquisition for expert systems*. London: Kogan Page.

Hatano, G. and Inagaki, K. (1986). “Two courses of expertise.” *Child Development and Education in Japan*, 262–272.

Haughey, D. W. (November 2000). “Leveraging Marine Corps experience.” *Marine Corps Gazette*, 45–46.

Hayes, J. R. (1985). “Three problems in teaching general skills.” In S. F. Chipman, J. W. Segal, and R. Glaser (Eds.), *Thinking and learning skills: Research and open questions* (vol. 2, 391–405). Hillsdale, NJ: Lawrence Erlbaum Associates.

Hayes-Roth, F., Waterman, D. A., and Lenat, D. B. (1983). *Building expert systems*. Reading, MA: Addison-Wesley.

Hernandez-Serrano, J. and Jonassen, D. H. (2003). “The effects of case libraries on problem solving.” *Journal of Computer Assisted Learning*, 19, 103–114.

Hesketh, B. and Ivancic, K. (2002). “Enhancing performance through training.” In S. Sonnentag (Ed.), *Psychological management of individual performance* (247–265). Chichester, England: Wiley.

Hoffman, R. R. (Summer 1987). “The problem of extracting the knowledge of experts from the perspective of experimental psychology.” *AI Magazine*, 8, 53–67.

Hoffman, R. R. (1991). “Human factors psychology in the support of forecasting: The design of advanced meteorological workstations.” *Weather and Forecasting*, 6, 98–110.

Hoffman, R. R. (Ed.) (1992). *The psychology of expertise: Cognitive research and empirical AI.* Mahwah, NJ: Lawrence Erlbaum Associates.

Hoffman, R. R. (1997). “How to doom yourself to repeat the past: Some reflections on the history of cognitive technology.” *Cognitive Technology*, 2, 4–15.

Hoffman, R. R. (1998). “How can expertise be defined?: Implications of research from cognitive psychology.” In R. Williams, W. Faulkner, and J. Fleck (Eds.), *Exploring expertise* (81–100). New York: Macmillan.

Hoffman, R. R. (September 2002). “An empirical comparison of methods for eliciting and modeling expert knowledge.” In *Proceedings of the 46th Meeting of the Human Factors and Ergonomics Society* (482–486). Santa Monica, CA: Human Factors and Ergonomics Society.

Hoffman, R. R. (2003). “Use of concept mapping and the critical decision method to support human-centered computing for the intelligence community.” Report, Institute for Human and Machine Cognition, Pensacola, FL.

Hoffman, R. R. (2003). “Knowledge recovery.” Report, Institute for Human and Machine Cognition, Pensacola, FL.

Hoffman, R. R. (Ed.) (2007). “Expertise out of context.” In: *Proceedings of the Sixth International Conference on Naturalistic Decision Making*. Boca Raton, FL: Taylor and Francis.

Hoffman, R. R., Coffey, J. W., and Carnot, M. J. (November 2000). “Is there a fast track into the black box?: The Cognitive Modeling Procedure.” Poster presented at the 41st Annual Meeting of the Psychonomics Society. New Orleans, LA.

Hoffman, R. R., Coffey, J. W., and Ford, K. M. (2000). “A case study in the Research Paradigm of Human-Centered Computing: Local expertise in weather forecasting.” Report to the National Technology Alliance on the Contract, Human-Centered System Prototype. Institute for Human and Machine Cognition. Pensacola, FL.

Hoffman, R. R., Crandall, B., and Shadbolt, N. (1998). “A case study in cognitive task analysis methodology: The critical decision method for the elicitation of expert knowledge.” *Human Factors*, 40, 254–276.

Hoffman, R. R. and Deffenbacher, K. (1992). “A brief history of applied cognitive psychology.” *Applied Cognitive Psychology*, 6, 1–48.

Hoffman, R. R. and Deffenbacher, K. A. (1993). “An analysis of the relations of basic and applied science.” *Ecological Psychology*, 5, 315–352.

Hoffman, R. R., Feltovich, P. J., and Ford, K. M. (1997). “A general framework for conceiving of expertise and expert systems in context.” In P. J. Feltovich, K . M. Ford, and R. R. Hoffman (Eds.), *Expertise in context: Human and machine* (543–580). Menlo Park, CA: AIII/MIT Press.

Hoffman, R. R. and Fiore, S. M. (May/June 2007). “Perceptual (Re)learning: A leverage point for Human-Centered Computing.” *IEEE Intelligent Systems*, 79–83.

Hoffman, R. R., Ford, K. M., and Coffey, J. W. (2000). *The Handbook of Human-Centered Computing*. Report, Institute for Human and Machine Cognition. Pensacola, FL.

Hoffman, R. R. and Hanes, L. F. (July-August 2003). "The boiled frog problem." *IEEE Intelligent Systems*, 68–71.

Hoffman, R. R. and Lintern, G. (2006). "Eliciting and representing the knowledge of experts." In K. A. Ericsson, N. Charness, P. Feltovich, and R. Hoffman, (Eds.), *Cambridge Handbook of Expertise and Expert Performance* (203–222). New York: Cambridge University Press.

Hoffman, R. R. and Militello, L. (2008). *Perspectives on cognitive task analysis: Historical origins and modern communities of practice.* Boca Raton, FL: CRC Press/Taylor and Francis.

Hoffman, R. R., Shadbolt, N. R., Burton, A. M., and Klein, G. (1995). "Eliciting knowledge from experts: A methodological analysis." *Organizational Behavior and Human Decision Processes*, 62, 129–158.

Hoffman, R. R. and Trafton, G. (forthcoming). "Minding the weather: How expert forecasters think."

Hoffman, R. R. and Woods, D. D. (Guest Editors) (2000). "Cognitive task analysis." Special Issue of *Human Factors*, 42, 1–95.

Hoffman, R. R., Ziebell, D., Fiore, S. M., and Becerra-Fernandez, I. (2008). "Knowledge mangement revisited." *IEEE Intelligent Systems*, 23, 84–88.

Hollnagel, E., Hoc, J.-M., and Cacciabue, P. C. (1996). "Expertise and technology: I have a feeling we're not in Kansas anymore." In J.-M. Hoc, P. C. Cacciabue, and E. Hollnagel, E. (Eds.), *Expertise and technology: Cognition and human-computer cooperation* (279–286). Mahwah, NJ: Lawrence Erlbaum Associates.

Hollnagel, E. and Woods, D. D. (1983). "Cognitive Systems Engineering: New wine in new bottles." *International Journal of Man-Machine Studies*, 18, 583–600.

Hutchins, E. (1995). *Cognition in the wild*. Cambridge, MA: MIT Press.

IAEA. (2006). "Risk management of knowledge loss in nuclear industry organizations."

Jenkins, J. J. (1979). "Four points to remember: A tetrahedral model of memory experiments." In L. S. Cermack and F. I. M. Craik (Eds.), *Levels of processing in human memory* (429–446). Menlo Park, CA: AAAI/MIT Press.

Jonassen, D. H. (2007). "What makes scientific problems difficult?" In D.H. Jonassen (Ed.), *Learning to solve complex, scientific problems* (3–23). Mahwah, NJ: LawrenceErlbaum Associates.

Klahr, D. (Ed.) (1976). *Cognition and instruction*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Klahr, D. and Kotovsky, K. (Eds.) (1989). *Complex information processing: The impact of Herbert A. Simon.* Mahwah, NJ: Lawrence Erlbaum Associates.

Klein, D. (2007). Interview with Nuclear Regulatory Commission Chairman Dale Klein at the 2007 Women in Nuclear Conference. [Downloaded 6 September 2007 from http://video.google.com/videoplay?docid=3549043670358279894]

Klein, G. (1992). “Using knowledge elicitation to preserve corporate memory.” In R. R. Hoffman (Ed.), *The psychology of expertise: Cognitive research and empirical AI* (170–190). Mahwah, NJ: Lawrence Erlbaum Associates.

Klein, G. (1998). *Sources of power: How people make decisions*. Cambridge, MA: MIT Press.

Klein, G. (2002). “Coaching others to develop strong intuitions.” Chapter 13. In G. Klein (Author): *Intuition at work* (208–226). New York: Doubleday.

Klein, G. (2003). *The power of intuition*. New York: Doubleday.

Klein, G. A., Calderwood, R., and MacGregor, D. (1989). “Critical decision method for eliciting knowledge.” *IEEE Transactions on Systems, Man, and Cybernetics*, 19, 462–472.

Klein, G. A. and Hoffman, R. R. (1992). “Seeing the invisible: Perceptual-cognitive aspects of expertise.” In M. Rabinowitz (Ed.), *Cognitive science foundations of instruction* (203–226). Mahwah, NJ: Lawrence Erlbaum Associates.

Klein, G. and Hoffman, R. R. (2008). “Macrocognition, mental models, and cognitive task analysis methodology.” In J. M. Schraagen (Ed.), *Macrocognition: Proceedings of the Seventh International Conference on Naturalistic Decision Making*. London: Ashgate. In production.

Klein, G., Orasanu, J., Calderwood, R., and Zsambok, C. E. (Eds.) (1993). *Decision making in action: Models and methods*. Norwood, NJ: Ablex.

Klein, G. and Zsambok, C. (Eds.) (1995). *Naturalistic decision making*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Knorr-Cetina, K. D. (1981). *The manufacture of knowledge*. Oxford: Pergamon.

Knorr-Cetina, K. D. and Mulkay, M. (1983). *Science observed*. Berkeley Hills, CA: Sage.

Konradt, U. (1995). “Strategies of failure diagnosis in computer-controlled manufacturing systems: Empirical analysis and implications for the design of adaptive decision support systems.” *International Journal of Human-Computer Studies*, 43, 503–521.

Koopman, P. and Hoffman, R. R. (November-December 2003). “Work-arounds, make-work, and kludges.” *IEEE: Intelligent Systems*, 70–75.

LaFrance, M. (1992). “Excavation, capture, collection, and creation: Computer scientists’ metaphors for eliciting human expertise.” *Metaphor and Symbolic Activity*, 7, 135–156.

Lambe, P. (2007). *Organizing knowledge: Taxonomies, knowledge, and organizational effectiveness.* Oxford, England: Chandos.

Lave, J. (1988). *Cognition in practice: Mind, mathematics, and culture in everyday life.* Cambridge: Cambridge University Press.

Leonard, D. (September 2004). "Deep smarts." *Harvard Business Review*, 82, 88–97, 137.

Leonard, D. and Swap, W. (2005). *Deep smarts: How to cultivate and transfer enduring business wisdom.* Boston, MA: Harvard Business School.

Lesgold, A. (2001). "The nature and methods of learning by doing." *American Psychologist*, 56, 964–973.

Lesgold, A. M., Lajoie, S. P., Bunzo, M., and Eggan, G. (1992). "SHERLOCK: A coached practice environment for an electronics troubleshooting job." In J. Larkin and R. Chabay (Eds.), *Computer assisted instruction and intelligent tutoring systems: Shared issues and complementary approaches* (201–238). Hillsdale, NJ: Lawrence Erlbaum Associates.

Lesgold, A. and Nahemow, M. (2001). "Tools to assist learning by doing: Achieving and assessing efficient technology for learning." In D. Klahr and S. Carver (Eds.), *Cognition and instruction: Twenty-five years of progress.* Mahwah, NJ: Lawrence Erlbaum Associates.

Lester, J. C., Vicari, R. M., and Paraquacu, F. (Eds.) (2004). *Intelligent tutoring systems*. New York: Springer-Verlag.

Linou, N. and Kontogiannis, T. (2004). "The effect of training systemic information on the retention of fault-finding skills in manufacturing industries." *Human Factors and Ergonomics in Manufacturing*, 14(2), 197–217.

Lintern, G. (2003). "Tyranny in RULES, autonomy in maps: Closing the safety management loop." In R. Jensen (Ed.), *Proceedings of the Twelfth International Symposium on Aviation Psychology* (719–724). Dayton, OH: Wright State University.

Lintern, G., Diedrich, F. J., and Serfaty, D. (2002). "Engineering the community of practice for maintenance of organizational knowledge." *Proceedings of the IEEE 7th Conference on Human Factors and Power Plants* (6.7–6.13). New York: IEEE.

Lintern, G., Miller, D., and Baker, K. (2002). "Work centered design of a USAF mission planning system." In *Proceedings of the Human Factors and Ergonomics Society 46th Annual Meeting* (531–535). Santa Monica, CA: Human Factors and Ergonomics Society.

Magill, R. A. and Hall, K. G. (1990). "A review of the contextual interference effect in motor skill acquisition." *Human Movement Science*, 9, 241–249.

Maglio, P. P., Kandogan, E., and Haber, E. (2003). "Distributed cognition and joint activity in collaborative problem solving." In *Proceedings of the Twenty-fifth Annual Conference of the Cognitive Science Society.* Boston, MA: Lawrence Erlbaum Associates.

McDonald, N., Corrigan, S., and Ward, M. (2002). "Cultural and organizational factors in system safety: Good people in bad systems." *Proceedings of the 2002 International Conference on Human-Computer Interaction in Aeronautics (HCI-Aero 2002)* (205–209). Menlo Park, CA: American Association for Artificial Intelligence Press.

McGraw, K. L. and Harbison-Briggs, K. (1989). *Knowledge acquisition: Principles and guidelines.* Englewood Cliffs, NJ: Prentice-Hall.

Means, B. and Gott, S. P. (1988). “Cognitive task analysis as a basis for tutor development: Articulating abstract knowledge representations.” In J. Psotka, L. D. Massey, and S. A. Mutter (Eds.), *Intelligent tutoring systems: Lessons learned* (35–57). Hillsdale, NJ: Lawrence Erlbaum Associates.

Mieg, H. A. (2000). *The social psychology of expertise.* Mahwah, NJ: Lawrence Erlbaum Associates.

Militello, L. G., and Hutton, R. J. B. (1998). “Applied Cognitive Task Analysis (ACTA): A practitioner’s toolkit for understanding cognitive task demands.” *Ergonomics*, 41, 1618–1641.

Miller, C. S., Lehman, J. F., and Koedinger, K. R. (1999). “Goals and learning in microworlds.” *Cognitive Science*, 23, 305–336.

Mistrell, J. (1999). “Expertise in teaching.” In R. J. Sternberg and J. A. Horvath (Eds.), *Tacit knowledge in processional practice* (215–230). Mahwah, NJ: Lawrence Erlbaum Associates.

Morris, C. D., Bransford, J. D., and Franks, J. J. (1977). “Levels of processing versus transfer appropriate processing.” *Journal of Verbal Learning and Verbal Behavior*, 16, 519–533.

Mumaw, R. J., Roth, E. M., Vicente, K. J., and Burns, C. M. (2000). “There is more to monitoring a nuclear power plant than meets the eye.” *Human Factors*, 42, 36–55.

Naikar, N. and Sanderson, P. M. (2001). “Evaluating system design proposals with work domain analysis.” *Human Factors*, 43, 529–542.

Naikar, N. and Saunders, A. (2003). “Crossing the boundaries of safe operation: A technical training approach to error management.” *Cognition Technology and Work*, 5, 171–180.

National Aeronautics and Space Administration. (NASA) (2003). *NASA Workforce Analysis Report.* Washington, DC: National Aeronautics and Space Administration.

National Institutes of Health. (2001). “Plan for Increasing the Number of Underrepresented Minorities Trained in Genomics Research.” [http://www.genome.gov/10001661] Downloaded 25 June 2005.

National Public Radio, Inc. (March 22, 2005). “Loss of line workers.” Morning Edition. Washington, DC: National Public Radio.

Neale, I. M. (1988). “First generation expert systems: A review of knowledge acquisition methodologies.” *Knowledge Engineering Review*, 3, 105–146.

Nonaka, I. and Takeuchi, H. (1995). *The knowledge creating company*. New York: Oxford University Press.

North American Electric Reliability Council. (2006). 2006 Long Term Reliability Assessment. Report of the Reliability Assessment Subcommittee. Washington, DC: North American Electric Reliability Council. [downloaded from http://www.nerc.com/~filez/rasreports.html on 7 September 2007]

Novak, J. D. and Gowin, D. B. (1984). *Learning how to learn*. New York: Cambridge University Press.

O'Dell, C. and Grayson, C. J. (1998). *If we only knew what we know: The transfer of internal knowledge and best practice.* New York: The Free Press.

Orr, J. E. (1996). *Talking about machines: An ethnography of a modern job.* New York: Cornell University Press.

Palincsar, A. P., Spiro, R. J., Kucan, L., Magnusson, S. J., Collins, B. P., Hapgood, S., Ramchandran, A., and DeFrance, N. (in press). "Research to practice: Designing a hypermedia environment to support elementary school teachers' learning in robust comprehension instruction." In D. McNamara (Ed.), *Reading comprehension strategies: Theory, interventions, and technologies.* Mahwah, NJ: Lawrence Erlbaum. Associates

Patrick, J. (1993). "Cognitive aspects of fault-finding training and transfer." *Le Travail Humain*, 56, 187–209.

Pilot Study for Capturing Undocumented Knowledge: Application at the EPRI NDE Center. EPRI, Palo Alto, CA: 2003. 1008456.

Pliske, R., Crandall, B., and Klein, G. (2004). "Competence in weather forecasting." In K. Smith, J. Shanteau, and P. Johnson (Eds.), *Psychological investigations of competent decision making* (40–70). Cambridge: Cambridge University Press.

Polson, M. and Richardson, J. (Eds.) (1988). *Foundations of intelligent tutoring systems.* Mahwah, NJ: Lawrence Erlbaum Associates.

Poulymenakou, A., Cornford, T., and Whitley, E. A. (1992). "Knowledge acquisition for organizational problem solving: Developing expert systems and beyond." *Expert Systems with Applications*, 5, 121–130.

Prerau, D. (1989). *Developing and managing expert systems: Proven techniques for business and industry.* Reading, MA: Addison Wesley.

Pringle, D. (January 7, 2003). "Learning gurus adapt to escape corporate axes." *The Wall Street Journal*, B1.

Proctor, R. W. and Vu, K. P.-L. (2006). "Laboratory studies of training, skill acquisition, and the retention of performance." In K. A. Ericsson, N. Charness, P. Feltovich, and R. Hoffman (Eds.), *Cambridge Handbook of Expertise and Expert Performance* (265–286) New York: Cambridge University Press.

Raeth, P. G. (Ed.) (1990). *Expert systems*. New York: IEEE Press.

Rasmussen, J. (1985). "The role of hierarchical knowledge representation in decision-making and system-management." *IEEE Transactions on Systems, Man, and Cybernetics*, SMC-15, 234–243.

Rasmussen, J. (1986). *Information processing and human-machine interaction: An approach to cognitive engineering*. Amsterdam: North-Holland.

Rasmussen, J. (1992). "Use of field studies for design of workstations for integrated manufacturing systems." In M. Helander and N. Nagamachi (Eds.), *Design for* *manufacturability: A systems approach to concurrent engineering and ergonomics* (317–338). London: Taylor and Francis.

Rasmussen, J., Petersen, A. M., and Goodstein, L. P. (1994). *Cognitive systems engineering*. New York: John Wiley.

Real-Time Expert Knowledge Acquisition and Transfer. EPRI, Palo Alto, CA: 2004. 1009581.

Renard, G. (1968). *Guilds in the Middle Ages*. New York: A. M. Kelley.

Resnick, M. R. (1994). *Turtles, termites, and traffic jams.* Cambridge, MA: MIT Press.

Rook, F. W. and Croghan, J. W. (1989). "The knowledge acquisition activity matrix: A systems engineering conceptual framework." *IEEE Transactions on Systems, Man, and Cybernetics*, 19, 586–597.

Salas, E. and Cannon-Bowers, J.A. (2001). "The science of training: A decade of progress." *Annual Review of Psychology*, 52, 471-499.

Salas, E. and Klein, G. (Eds.) (2001). *Linking expertise and naturalistic decision making*. Mahwah, NJ: Lawrence Erlbaum Associates.

Salas E., Nichols, D.R., and Driskell, J. E. (2007). "Testing three team training strategies in intact teams: A meta-analysis." *Small Group Research*, 38, 471–488.

Schank, R. C. and Farrel, R. (1988). "Creativity in education: A standard for computer-based teaching." *Machine Mediated Learning*, 2, 175–194.

Schaper, N. and Sonnentag, K. (1998). "Analysis and training of diagnostic expertise in complex technical domains." *European Journal of Work and Organizational Psychology*, 7, 479–498.

Schmidt, L. and Luczak, H. (2000). "Knowledge representation for engineering design based on a cognitive model." In *Proceedings of the IEA 2000/HFES 2000 Congress* (vol. 1, 623–626). Santa Monica, CA: Human Factors and Ergonomics Society.

Schmidt, R. A. and Bjork, R. A. (1992). "New conceptualizations of practice: Common principles in three paradigms suggest new concepts for training." *Psychological Science*, 3, 207–217.

Schmidt, R. A., Young, D. E., Swinnen, S., and Shapiro, D. C. (1989). "Summary knowledge of results for skill acquisition: Support for the guidance hypothesis." *Journal of Experimental Psychology: Learning, Memory and Cognition*, 15, 352–359.

Schooler, L. J. and Anderson, J. R. (1990). "The disruptive potential of immediate feedback." In *Proceedings of the Cognitive Science Society*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Scribner, S. (1984). "Studying working intelligence." In B. Rogoff and S. Lave (Eds.), *Everyday cognition: Its development in social context* (9–40). Cambridge: Harvard University Press.

Shadbolt, N. R. and Burton, A. M. (1990). "Knowledge elicitation techniques: Some experimental results." In K. L. McGraw and C. R. Westphal (Eds.), *Readings in knowledge acquisition* (21–33). New York: Ellis Horwood.

Shanteau, J. (1992). “Competence in experts: The role of task characteristics.” *Organizational Behavior and Human Decision Processes*, 53, 252–266.

Shortliffe, E. H. (1976). *Computer-based medical consultations: MYCIN*. New York: Elsevier.

Simon, H. A. and Hayes, J. R. (1976). “Understanding complex task instructions.” In D. Klahr (Ed.), *Cognition and instruction* (51–80). Hillsdale, NJ: Lawrence Erlbaum Associates.

Skinner, B. F. (1958). “Teaching machines.” *Science*, 129, 969–977.

Skinner, B. F. (1968). *The technology of teaching*. New York: Appleton-Century-Crofts.

Smith, P. J. (2003). “Workplace learning and flexible delivery.” *Review of Educational Research*, 73(1), 53–88.

Snowden, D. and Boone, M. (2007). “A leader’s framework for decision making.” *Harvard Business Review*, 85, 69–76.

Sonnentag, S. (2000). “Excellent performance: The role of communication and cooperation processes.” *Applied Psychology: An International Review*, 49, 483–497.

Sonnentag, S. and Lange, I. (2002). “The relationship between high performance and knowledge about how to master cooperation situations.” *Applied Cognitive Psychology*, 16, 491–508.

Sonnentag, S., Niessen, C., and Volmer, J. (2006). “Expertise in software design.” In K. A. Ericsson, N. Charness, P. Feltovich, and R. Hoffman (Eds.), *Cambridge Handbook of Expertise and Expert Performance* (373–387). New York: Cambridge University Press.

Spiro, R. J., Collins, B. P., Thota, J. J., and Feltovich, P. J. (2003). “Cognitive flexibility theory: Hypermedia for complex learning, adaptive knowledge application, and experience acceleration.” *Educational Technology*, 44, 5–10.

Spiro, R. J., Feltovich, P. J., Coulson, R. L., and Anderson, D. (1989). “Multiple analogies for complex concepts: Antidotes for analogy-induced misconception in advanced knowledge acquisition.” In S. Vosniadou and A. Ortony (Eds.), *Similarity and analogical reasoning* (498–531). Cambridge, MA: Cambridge University Press.

Spiro, R. J., Feltovich, P. J., Jacobson, M. J., and Coulson, R. L. (1992). “Cognitive flexibility, constructivism, and hypertext: Random access instruction for advanced knowledge acquisition in ill-structured domains.” In T. Duffy and D. Jonassen (Eds.), *Constructivism and the technology of instruction* (57–75). Hillsdale, NJ: Lawrence Erlbaum Associates.

Spradley, J. P. (1979). *The ethnographic interview*. New York: Holt, Rinehart and Winston.

Stefik, M., Aikins, J., Balzer, R., Benoit, J., Birnbaum, L., Hayes-Roth, F., and Sacerdoti, E. (1982). “The organization of expert systems: A tutorial.” *Artificial Intelligence*, 18, 135–173.

Stein, E. W. (1997). “A look at expertise from a social perspective.” In P. J. Feltovich, K. M. Ford, and R. R. Hoffman (Eds.), *Expertise in context* (181–194). Cambridge: MIT Press.

Sternberg, R. J. and Frensch, P. A. (Eds.) (1991). *Complex problem solving: Principles and mechanisms.* Mahwah, NJ: Lawrence Erlbaum Associates.

Suchman, L. (1987). *Plans and situated actions: The problem of human-machine communication.* Cambridge: Cambridge University Press.

Taylor, F. W. (1911). *Principles of scientific management*. New York: Harper and Row.

Valkeavaara, T. (1999). "Sailing in calm waters doesn't teach: Constructing expertise through problems in work—the case of Finnish human resource developers." *Studies in Continuing Education*, 21, 177–196.

Vicente, K. J. (1999). *Cognitive work analysis: Towards safe, productive, and healthy computer-based work.* Mahwah, NJ: Lawrence Erlbaum Associates.

Vicente, K. J., Christoffersen, K., and Pereklita, A. (1995). "Supporting operator problem solving through ecological interface design." *IEEE Transactions on Systems, Man, and Cybernetics*, SMC-25, 529–545.

Vosniadou, S. and Ortony, A. (1989). *Similarity and analogical reasoning*. Cambridge, UK: Cambridge University Press.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Wisher, R. A. and Fletcher, J. D. (2004). "The case for advanced distributed learning." *Information and Security: An International Journal*, 14, 17–25.

Woodworth, R. R. (1938a). "Practice and skill." Chapter 7. In R. S. Woodworth (Author), *Experimental psychology* (156–175). New York: Holt, Rinehart and Winston.

Woodworth, R. R. (1938b). "Transfer of training." Chapter 8. In R. S. Woodworth (Author), *Experimental psychology* (176–207). New York: Holt, Rinehart and Winston.

Woolf, B. P., Reid, J., Stillings, N., Bruno, M., Murray, D., Reese, P., Peterfreund, A., and Rath, K. (2002). "A general platform for inquiry learning." *Proceedings of the 6th International Conference in Intelligent Tutoring Systems* (ITS 2002). Biarritz, France; and San Sebastian, Spain.

Zachary, W., Neville, K., Fowlkes, J., and Hoffman, R. R. (March/April 2007). "Human total cost of ownership: The Penny Foolish Principle at work." *IEEE Intelligent Systems*, 22–26.

B
TRANSLATED TABLE OF CONTENTS

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

技術創新計劃：加速獲取任務關鍵型專業知識

研究藍圖

1016710

2008 年 12 月技術更新版

EPRI 專案經理

D. Ziebell

產品描述

專業知識之所以流失，原因在於員工所具備的未成文知識伴隨著員工的離去而失去，對此問題我們已有詳細描述，並進行了多方研究。但電力行業是否已盡其所能地獲取未成文知識，並將這些知識傳授給其他員工呢？ 本報告所述之研究是由電力科學研究院 (EPRI) 所做，根據該研究指出，大多數未成文知識其實是可以藉由訓練、顧問指導及其他經過實證的程序而進行有效轉移。但是，至於一般人公認的專家需要多長時間才能完成任務關鍵型專業知識的累積，以及累積時間能否縮短，卻依然是未知的。本專案旨在確定如何將加速專業知識與特殊知識獲取的方法提升到全新的水準。需要花時間掌握的工作內容是什麼？耗時數年才能獲取的高精通水準之工作的知識特性是什麼？

本報告所做的分析詳細闡明了如何獲取與核電廠領域類似以及不同之領域的專業知識。

結果和發現

對於核電廠領域極為重要的專家鑑定類型，我們知之甚少。因此，對於建構在其他行業領域中已成文的專家鑑定方法能否轉而用於核電廠行業這一問題，目前尚不明朗。電力行業專家技術鑑定目前一般由相當少數的個人依據一系列毫無系統性可言的特殊經驗來進行判定，原因在於這些極少數的個人曾多次經歷並正確地處理過一些罕見且具挑戰性的事件。

通常來說，培養一位一般人公認的專家至少需要 25 年的時間，花費數十萬美元的薪資與訓練費用。如能縮短時間，代表可節省下可觀的成本和降低風險。根據一位 EPRI 核電廠會員估計，若能將專家的未成文知識傳授給其他工程師可有效預防故障的發生，節約 10 萬美元的成本。EPRI 將探討如何將累積並傳授專業知識的時間減少至三分之一。本報告所述之專案還研究了某一實務領域中經驗豐富的核電廠行業工作人員，如何在一兩年的時間內成功轉變成為另一領域的專家。

挑戰和目的

本報告所述之研究與原理對於負責招聘、傳授與教育發電廠中執行任務關鍵型職能之個人的管理層與培訓人員而言極有益助。未來 5 - 10 年裏，40% – 70%

的勞動力人口將退休，在這種因勞動力人口發生巨大轉變而引發的壓力下，與專家知識與技能流失相關的問題將只可能嚴重加劇。

應用、數值和使用

本報告所述之藍圖會針對一或多個論證專案提出多項措施。在這些可行性建議之中，問卷調查可讓勞動力人口與知識流失的問題引起核電廠內部高級管理層與領導層關注，進而將問題的討論從當前的知識流失風險評估方法轉至更深入的細節研究。對於勞動力人口與專業知識問題及挑戰的廣泛認知，將能夠激勵各核電廠公司繼續不斷地努力，創造知識文化。現場研究與認知任務分析將拉開知識獲取過程的帷幕
(包括披露核電廠專家的知識、技能與策略)，之後這些知識可能會應用到培訓中去。與此同時，現場研究與認知任務分析所得的資料將會用於加速專業知識的獲取，包括棘手案例時間壓縮與決策制定活動。

EPRI 遠景

EPRI
針對專業知識流失的問題，將解決的重點放在研究、開發與測試實用的工具上，以期獲取有價值的未成文專業知識，讓核電廠工作人員能夠應用這些專業知識，使核電廠持續高效地運轉。2002 年公佈的《獲取能源行業工作人員有價值的未成文知識指南》（1004663
號報告）詳細闡述了問題的範圍以及透過問卷調查得出的解決問題的方法。《獲取並使用核能行業高價值的未成文知識：指南與方法》（1002896
號報告）闡述了有效應用這些方法的詳細過程。《即時專家知識獲取與傳授 -
需求與技術評估：自我誘導與自動知識獲取方法》（1009581
號報告）則更新了該過程，並新增關於簡化某類專家資訊流程的觀點。

方法

本報告的目的有三：

- 使用一般術語描述研究問題。針對負責處理最棘手的任務關鍵型技術問題之技術專家，如何將其所擁有的專業知識的進度加速並提升至新高度？
- 將專家流失的問題與勞動力人口老齡化這一更為普遍的挑戰加以區別，勞動力人口老齡化會影響大多數核電廠所有的任務相關型活動。因應廣泛勞動力人口挑戰的知識管

理與培訓，對於因重要專家的流失而導致核電廠任務發生風險方面，並沒有將風險降至最低的作用。

- 建立藍圖來完成解決問題的研究。

關鍵字

老齡化人力

知識管理

知識保存

目錄

_1_ 引言 1-1

背景 1-1

目的與意圖 1-2

方法 1-2

_2_ 特殊專業知識問題 2-1

核電廠專業知識範圍 2-1

問題 2-2

方法 2-2

專業術語 2-4

_3_ 文獻審查 3-1

心理學專業知識研究 3-1

培訓 3-2

教育心理學 3-2

博物學決策制定 3-2

知識管理 3-5

顧問指導 3-6

_4_ 核電廠領域過往研究應用 4-1

重新審視核電廠專業化：專業知識研究結論的相似性 4-1

時間跨度 4-2

因應日新月異的技術 4-2

重新審視核電廠專業化：選擇與培訓 4-3

_5_ 終審計劃的初始標準/成功因素 5-1

理論基礎 5-1

培訓要求 5-3

培訓必須將*轉移距離*縮至最短 5-3

培訓必須提高靈活性與適應性 5-3

培訓資料 5-4

培訓程序 5-4

適應性與感知學習 5-4

推理能力 5-5

回饋 5-6

時間壓縮 5-6

決策制定能力 5-8

團隊合作能力與人際關係能力 5-10

6 工作會議 6-1

會議基本原理 6-1

專家與傑出專家特徵 6-2

定義專家與*傑出專家*的特徵 6-5

組織背景 6-8

知識流失風險評估 6-9

7 加速專業知識獲取的計劃 7-1

試驗與論證 7-1

傑出專家與專家案例研究文集編制（短期） 7-1

針對知識管理與專業知識流失的核電廠經理調查（短期） 7-1

潛在傑出專家選擇方法調查（中期） 7-2

現場研究 7-2

認知任務分析（短期） 7-2

持續獲取傑出專家的知識（短期） 7-2

棘手案例採集與分類（中期） 7-3

選擇研究（基於選擇方法調查）（長期） 7-3

加強儲備專家的回饋（短期） 7-3

後續行動審查 7-3

Pre-Mortem 7-3

培訓與學習 7-4

評估學習障礙（長期）.......... 7-4
在職培訓（中期）.......... 7-4
結論.......... 7-4
A 參考文獻 A-1

技术创新计划：加速获取任务关键型专业知识

研究蓝图

1016710

技术更新版 2008 年 12 月

EPRI 项目经理

D. Ziebell

产品描述

专业知识流失问题产生的原因，在于员工所具备的未成文知识伴随着员工的离去而失去，对此问题我们已有详细描述，并进行了大量研究。但电力行业是否已尽其所能地获取未成文知识，并将这些知识传授给其他员工呢？

本报告所述之电力科学研究院 (EPRI)
所做的研究表明，大多数未成文知识其实是可以通过培训、顾问指导及其他经证明有效的程序而进行有效传播。但是，至于一般人公认的专家需要多长时间才能完成任务关键型专业知识的积累，以及积累时间能否缩短，却依然是未知的。本项目旨在确定如何将加速专业知识与特殊知识获取的方法提升到全新的水平。需要花时间掌握的工作内容是什么？耗时数年才能获取的高精通水平之工作的知识特性是什么？

本报告所做的分析详细阐明了如何获取与核电厂领域类似以及不同领域的专业知识。

结果和发现

对于核电厂领域极为重要的专家鉴定类型，我们知之甚少。因此，对于构建在其他行业领域中已成文的专家鉴定的方法能否转而用于核电厂行业这一问题，目前尚不明朗。电力行业专家技术鉴定目前一般由相当少数的个人依据一系列毫无系统性可言的特殊经验而判定，原因在于这些极少数的个人曾多次经历并正确地处理过一些罕见且具挑战性的事件。

通常情况下，培养一名一般人公认的专家至少需要 25
年的时间，花费数十万美元的薪资与培训费用。如能缩短时间，意味着可观的成本降低和风险的降低。根据一名 EPRI
核电厂会员估计，通过将专家的未成文知识传授给其他工程师可有效预防故障的发生，节约 10 万美元的成本。EPRI
全力探寻如何将积累并传授专业知识的时间减少三分之一。本报告所述之项目还研究了某一实践领域中经验丰富的核电厂行业工作人员，如何在一两年的时间内成功转变成为另一领域的专家。

挑战和目的

本报告所述之研究与原理对于负责招聘、传授与教育发电厂中执行任务关键型职能之个人的管理层与培训人员而言极有益助。未来 5 - 10 年里，40% – 70% 的劳动力人口将退休，在这种因劳动力人口发生巨大转变而引发的压力下，与专家知识与技能流失相关的问题将只可能严重加剧。

应用、数值和使用

本报告所述之计划针对一个或多个论证项目提出若干措施。在这些可行性建议之中，问卷调查将令劳动力人口与知识流失的问题引起核电厂内部高级管理层与领导层的关注，从而将问题的讨论从当前的知识流失风险评估方法转至更深入的细节研究。对劳动力人口与专业知识问题及挑战的广泛认知，将激励各核电厂公司继续不断地努力，创造知识文化。现场研究与认知任务分析将拉开知识获取过程的帷幕（包括披露核电厂专家的知识、技能与策略），这些知识可能会应用到培训中去。与此同时，现场研究与认知任务分析生成的资料将会用于加速专业知识的获取，包括棘手案例时间压缩与决策制定活动。

EPRI 远景

EPRI 针对专业知识流失的问题，将解决的重点放在实用工具的研究、开发与测试上，以期获取有价值的未成文专业知识，让核电厂工作人员应用这些专业知识，使核电厂公司持续高效地运行。2002 年公布的《获取能源行业工作人员有价值的未成文知识指南》（1004663 号报告）详细阐述了问题的范围以及通过问卷调查得出的解决问题的方法。《获取并使用核能行业高价值的未成文知识：指南与方法》（1002896 号报告）阐述了有效应用这些方法的详细过程。《实时专家知识获取与传授 - 需求与技术评估：自我诱导与自动知识获取方法》（1009581 号报告）对该过程进行了更新，并新增关于简化某类专家信息流程的观点。

方法

本报告的目的有三：

- 使用一般术语描述研究问题。针对负责处理最棘手的任务关键型技术问题之技术专家，如何将其拥有的专业知识的进度加速并提升至新高度？
- 将专家流失的问题与劳动力人口老龄化这一更为普遍的挑战加以区别，劳动力人口老龄化会影响大多数核电厂公司所有的任务相关型活动。应应广泛的劳动力人口挑战的知识管理与培训，对于因重要专家的流失而导致的核电厂任务发生风险方面，并没有将风险降至最低的作用。
- 建立完成解决专家与知识流失问题之研究的计划。

关键词

老龄化劳动力人口

知识管理

知识保留

目录

1 引言 1-1
背景 1-1
目的与意图 1-2
方法 1-2
2 特殊专业知识问题 2-1
核电厂专业知识范围 2-1
问题 2-2
方法 2-2
专业术语 2-4
3 文献审查 3-1
心理学专业知识研究 3-1
培训 3-2
教育心理学 3-2
博物学决策制定 3-2
知识管理 3-5
顾问指导 3-6
4 核电厂领域过往研究应用 4-1
重新审视核电厂专业化：专业知识研究结论的相似性 4-1
时间跨度 4-2
应对日新月异的技术 4-2
重新审视核电厂专业化：选择与培训 4-3

5 终审计划的初始标准/成功因素 5-1
理论基础 5-1
培训要求 5-3
培训必须将*转移距离*降至最短 5-3
培训必须提高灵活性与适应性 5-3
培训资料 5-4
培训程序 5-4
适应性与感知学习 5-4
推理能力 5-5
反馈 5-6
时间压缩 5-6
决策制定能力 5-8
团队协作能力与人际关系能力 5-10
6 工作会议 6-1
会议基本原理 6-1
专家与杰出专家特征 6-2
定义专家与*杰出专家*的特征 6-5
组织背景 6-8
知识流失风险评估 6-9
7 加速专业知识获取的计划 7-1
试验与论证 7-1
杰出专家与专家案例研究文集编制（短期） 7-1
针对知识管理与专业知识流失的核电厂经理调查（短期） 7-1
潜在杰出专家选择方法调查（中期） 7-2
现场研究 7-2
认知任务分析（短期） 7-2
持续获取杰出专家的知识（短期） 7-2
棘手案例采集与分类（中期） 7-3

选择研究（基于选择方法调查）（长期）......7-3
加强储备专家的反馈（短期）......7-3
后续行动审查......7-3
Pre-Mortem......7-3
培训与学习......7-4
评估学习障碍（长期）......7-4
在职培训（中期）......7-4
结论......7-4
A 参考文献......A-1

Programme d'innovation technologique : Accélération de la concrétisation des connaissances spécialisées, essentielles à la mission

Un carnet de route en recherche

1016710

Mise à jour technique, décembre 2008

Directeur de projet EPRI

D. Ziebell

DESCRIPTION DU PRODUIT

Le problème de la perte des connaissances, résultant du départ d'employés qui emportent avec eux des connaissances non documentées, a été bien décrit et a fait l'objet de nombreuses recherches. Mais l'industrie a-t-elle fait tout ce qu'elle pouvait pour récupérer les connaissances non documentées et les transmettre à d'autres employés ?

Les recherches entreprises par l'Electric Power Research Institute (EPRI) et décrites au présent rapport indiquent que la plupart des connaissances non documentées peuvent en effet être transférées efficacement au moyen de la formation, du mentorat et d'autres méthodes éprouvées. Reste cependant à savoir quel est le temps nécessaire pour que des experts reconnus acquièrent les connaissances spécialisées essentielles à leur mission et si cette période de temps peut être condensée. Ce projet avait pour but de déterminer comment les méthodes destinées à accélérer la concrétisation des connaissances spécialisées et des connaissances spécialisées extraordinaires pouvaient être ramenées à des niveaux entièrement nouveaux. Qu'est-ce qui, dans le travail même, est long à maîtriser ? Qu'est-ce qui, dans la nature du processus d'apprentissage, fait que la réalisation de niveaux élevés de compétence constitue un investissement sur plusieurs années ?

L'analyse présentée dans le présent rapport met en relief ce qui est connu sur la manière dont les connaissances spécialisées sont acquises dans des domaines qui sont à la fois semblables et différents des domaines des services publics.

Résultats et conclusions

Nous en connaissons très peu sur le type de jugement spécialisé qui est important dans le domaine des services publics. Par conséquent, il n'est pas évident que les méthodes de concrétisation de jugement spécialisé qui ont été documentées dans d'autres domaines soient transférables dans l'industrie des services publics. Le jugement expert technique dans l'industrie d'aujourd'hui résulte généralement de séquences non structurées, ponctuelles d'expériences connues de relativement peu de personnes, qui se sont trouvées opportunément présentes au bon endroit et ont ainsi fait l'expérience à maintes reprises d'événements rares et difficiles.

En général, il faut au moins 25 ans et un investissement de centaines de milliers de dollars en salaire et en formation pour créer un expert reconnu. Toutes les années qui peuvent être soustraites à ce total représenteraient une économie significative et une diminution des risques. Un des services membres d'EPRI estime que le transfert des connaissances non documentées de ses experts à d'autres ingénieurs économise 100 000 $ en défaillances évitées. L'EPRI cherche à comprendre comment réduire de trois fois le temps nécessaire pour obtenir les connaissances spécialisées. Le projet décrit au présent rapport a aussi examiné comment le personnel spécialisé d'un secteur technique peut devenir un expert dans un autre secteur en un ou deux ans.

Défis et objectifs

La recherche et les théories présentées dans ce rapport seront particulièrement utiles dans la gestion et la formation du personnel responsable de l'embauche, du transfert et de l'instruction des personnels qui exécutent des fonctions essentielles dans les centrales. Les problèmes associés à la perte des connaissances et des compétences spécialisées ne feront qu'augmenter en gravité à cause des tensions provoquées par des changements dramatiques dans la main-d'œuvre lorsque de 40 à 70 pour cent des effectifs prendront leur retraite au cours des 5 ou 10 prochaines années.

Applications, valeur et utilisation

L'orientation offerte dans ce rapport recommande plusieurs mesures en vue de l'élaboration d'un projet pilote ou plus. Parmi ces recommandations pouvant donner suite à des mesures, des études sur les problèmes de pertes de main-d'œuvre et de connaissances feront que la haute direction et le leadership des services publics en prendront conscience, amenant ainsi la discussion du problème à un niveau plus détaillé que les méthodes actuelles d'évaluation des risques face à la perte des connaissances. Une reconnaissance générale des problèmes et défis motivera des efforts permanents pour créer une culture du savoir. Des études sur le terrain et une analyse des activités d'apprentissage démarreront le processus de récupération des connaissances, révélant ainsi les connaissances, compétences et stratégies des experts des services publics, de manière à ce que ces connaissances spécialisées soient par la suite utilisées dans la formation. En même temps, des études sur le terrain et une analyse des activités d'apprentissage produiront une documentation qui peut être utilisée pour tenter d'accélérer la concrétisation des connaissances spécialisées, y compris des exercices de compression de temps et de prise de décision dans des cas épineux.

Perspective d'EPRI

La contribution d'EPRI à l'ensemble de solutions relatives à la perte de savoir a été orientée dans la recherche, le développement et l'essai d'outils pratiques pour la récupération de connaissances précieuses non documentées que le personnel des services publics met en application pour obtenir une performance durable. Un rapport de 2002, *Guidelines for Capturing Valuable Undocumented Knowledge from Energy Industry Personnel* (Lignes directrices pour la récupération de connaissances précieuses non documentées du personnel de l'industrie de l'énergie) (rapport 1004663), présente la portée du problème et étudie les méthodes en vue de le traiter. Le rapport *Capturing and Using High-Value Undocumented Knowledge in the Nuclear Industry: Guidelines and Methods* (Récupération et utilisation de connaissances inestimables non documentées dans l'industrie nucléaire : lignes directrices et méthodes) (rapport 1002896) offre un processus détaillé pour appliquer efficacement ces méthodes. Dans le rapport *Real-Time Expert Knowledge Acquisition and Transfer—Needs and Technology Assessment: Toward Self-Elicitation and Automated Knowledge Capture Methods* (Acquisition et transfert des connaissances spécialisées en temps réel - Évaluation des technologies et besoins : vers des méthodes d'autosubtilisation et d'autorécupération des connaissances) (rapport 1009581), le processus est mis à jour et on y offre un aperçu supplémentaire sur la façon d'assouplir le débit de certains types de renseignements des experts.

Approche

Ce rapport a trois buts :

- Décrire le problème à rechercher en termes généraux.Comment pouvons-nous atteindre plus rapidement des niveaux extraordinaires d'expertise chez les experts techniques qui ont pour tâche de traiter les problèmes techniques les plus difficiles et les plus essentiels ?Faire la différence entre le problème de la perte des experts et le défi plus général du vieillissement des effectifs qui touche la plupart des services publics dans presque toutes les activités liées à leur mission. La gestion du savoir et la formation qui répondent au défi global des effectifs ne feront rien ou très peu pour minimiser le risque posé par la perte des experts qui sont essentiels à la mission des services publics.
- Établir un plan de travail pour terminer la recherche en vue de traiter le problème.

Mots-clés

Vieillissement des effectifs
Gestion des connaissances
Maintien des connaissances

TABLE DES MATIERES

1 INTRODUCTION 1-1
- Historique 1-1
- But 1-2
- Méthode 1-2

2 LE PROBLEME DES CONNAISSANCES SPECIALISEES EXTRAORDINAIRES 2-1
- Domaines d'expertise dans les services publics 2-1
- Le problème 2-2
- Approche 2-2
- Terminologie 2-4

3 ETUDE DE LA DOCUMENTATION 3-1
- Études des connaissances spécialisées en psychologie 3-1
- Le secteur de la formation 3-2
- Le secteur de la psychologie de l'éducation 3-2
- Le secteur de la prise de décision naturaliste 3-2
- Le secteur de la gestion du savoir 3-5
- Mentorat 3-6

4 APPLICATION DES RECHERCHES ANTERIEURES AUX DOMAINES DES SERVICES PUBLICS 4-1
- Nouveau regard sur les spécialisations des services publics : Similitudes et conclusions des études sur les connaissances spécialisées 4-1
  - Échelle de temps 4-2
  - Faire face à la technologie en évolution 4-2
- Nouveau regard sur les spécialisations des services publics : La sélection par opposition à la formation 4-3

5 CRITERES INITIAUX/FACTEURS DE REUSSITE POUR UN PROGRAMME DEFINITIF 5-1
- Fondements théoriques 5-1
- Exigences de formation 5-3
  - La formation doit réduire la *distance du transfert* 5-3
  - La formation doit promouvoir flexibilité et adaptabilité 5-3
- Documents de formation 5-4
- Méthode de formation 5-4
  - Adaptabilité et apprentissage perceptuel 5-4
  - Capacité de raisonnement 5-5
  - Feedback 5-6
  - Compression de temps 5-6
  - Aptitudes à la prise de décision 5-8
  - Aptitudes au travail en équipe et au relationnel 5-10

6 LA REUNION DE TRAVAIL ... 6-1
Justification de la réunion ... 6-1
Caractéristiques des experts et super experts ... 6-2
Définition des caractéristiques des experts et *super experts* ... 6-5
Contexte organisationnel ... 6-8
Évaluation des risques de perte des connaissances ... 6-9

7 PLAN DE TRAVAIL POUR ACCELERER LA CONCRETISATION DES CONNAISSANCES SPECIALISEES ... 7-1
Essais et démonstrations ... 7-1
Mise au point d'un corpus d'études de cas d'experts et de super experts en action (court terme) ... 7-1
Étude de gestionnaires de services publics pour obtenir une vue d'ensemble de la gestion du savoir et de la perte des connaissances spécialisées (court terme) ... 7-1
Étude des méthodes de sélection des super experts potentiels (moyen terme) ... 7-2
Recherche sur le terrain ... 7-2
Analyse cognitive des tâches (court terme) ... 7-2
Récupération permanente des connaissances des super experts (court terme) ... 7-2
Rassemblement et catalogage des cas épineux (moyen terme) ... 7-3
Recherche de sélection (fondée sur une analyse des méthodes de sélection) (long terme) ... 7-3
Affiner le feedback donné aux experts potentiels (court terme) ... 7-3
Contrôles post-intervention ... 7-3
Pre-Mortem ... 7-3
Formation et apprentissage ... 7-4
Évaluation des obstacles à l'apprentissage (long terme) ... 7-4
Formation en cours d'emploi (moyen terme) ... 7-4
Conclusion ... 7-4

A REFERENCES ... A-1

テクノロジーイノベーションプログラム:
ミッションに重要な専門知識の急速な習得

研究ロードマップ

1016710

技術情報の改訂、2008年12月

EPRIプロジェクト マネージャー

D. Ziebell

成果品説明

知識喪失の問題、すなわち技術者が文書化されていない知識と共に離職してしまうことについては、多くの書物や研究が行われてきました。しかし産業界では、文書化されていない知識を他の技術者に引き継ぐための、全ての手段を講じているでしょうか？

Electric Power Research Institute (EPRI)
が実施した研究によると、文書化されていない知識の大半は、トレーニング、指導、及びその他の実証されたプロセスにより効果的に引き継ぐことが可能であることが示されています。ただし、エキスパートと認められる技術者がミッションに重要な専門知識を蓄積するまでにどのくらいの時間が必要なのか、またその期間を短縮できるのかについては、依然として不明です。専門知識とそれを習得する過程を大幅に短縮する方法はないものか、それを検証することがこのプロジェクトの目的でした。習得するまでに時間がかかる仕事とは、そもそもどのようなものでしょうか？
高レベルな能力を習得するのに何年も費やさなければならない仕事とは、どのようなものでしょうか？

このレポートにおける分析では、電力会社と類似の、またこれとは異なる分野のそれぞれにおいて、専門知識を習得する方法についてどのようなことが理解されているかについて焦点を当てます。

結果および発見
電力会社の分野においてどのような種類のエキスパートの判断が重要なのかについては、あまりよく知られていません。従って、エキスパートの判断に関して他の分野において文書化されている方法が、電力産業界にも応用可能かどうかも不明です。現在の産業界におけるエキスパートの技術的判断というのは、一般的に少数の技術者がその場その場で非構造的に経験した一連の内容によるものです。すなわち、普段は遭遇しないような難しい場面に繰り返し居合わせたことによる結果なのです。

通常、エキスパートと称されるようになるまでには、最低でも25年、それに何十万ドルもの給与と研修費用が費やされます。この所要期間のうちたとえ何年でも短縮できれば、かなりの節約及びリスク削減となります。EPRIに加盟しているある電力会社の推定によると、文書化されていないエキスパートの知識を他のエンジニアに引き継ぐことによって行われる故障防止は$100,000の節約に達するといいます。EPRIでは、エキスパートになるまでの所要期間を1/3短縮できるか否かを検討しています。電力会社のある部門で経験豊富な技術者がわずか1～2年で同じ会社の別部門のエキスパートになるための方法についても、このレポートで紹介するプロジェクトにおいて調査されています。

課題および目的

このレポートで示す研究および理論は、発電所でミッションに重要な機能に携わる技術者を雇用、異動、および教育する管理者および研修担当者にとって特に有益なものとなるでしょう。今後5～10年間で労働力全体の40～70%が退職するという状況にあたり、エキスパートの知識と技能の喪失に伴う問題は深刻さを増す一方です。

適用、価値、および実践

このレポートに示されるロードマップでは、1つ以上の実証プロジェクトに向けた対策をいくつか推奨しています。これらの対策可能な推奨のうち、電力会社内の高い管理及びリーダーシップレベルから見た労働力と知識の喪失の問題に焦点を当て、現状の知識喪失リスク評価の取り組みよりもさらに細部に踏み込んで考察を進めていきます。問題や課題が広く認識されることで、知識文化の創出に向けた継続的努力への意欲が高まるでしょう。実地調査と認知タスク分析から、電力会社のエキスパートが持つ知識、技能、戦略の見せる知識獲得のプロセスを立ち上げ、各者の専門知識がやがてトレーニングに利用されるようにもなります。同時に、実地調査と認知タスク分析からは、専門知識習得を急速に実施するための資料を作成することができます。これらの資料には厳しい状況下での時間圧縮や意思決定の実習などが含まれます。

EPRIの展望

知識喪失に対してEPRIが提示する一式の解決策では、文書化されていない貴重な知識を獲得するための実用的なツールを研究、開発、試験することに主眼を置き、このツールを技術者が電力会社で適用することで、持続可能なパフォーマンスが可能となります。2002年のレポート、*エネルギー産業界の技術者から文書化されていない貴重な知識を獲得するためのガイド*（レポート1004663）では、問題の範囲を規定し、その対処方法を調査しました。*原子力産業界においての文書化されていない高価値な知識の獲得及び使用：ガイドと方法（レポート1002896）では、上記の各方法を有効に適用するための詳細なプロセスを説明しています。リアルタイムエキスパート知識の習得及び譲渡—ニーズと技術評価：自己題存化及び自動知識獲得方法に向けて*（レポート1009581）では、上記プロセスが改定され、エキスパートからの特定情報の流れを円滑にするための追加の見識が提供されています。

アプローチ

このレポートには以下3つの目的があります。

- 研究可能な問題を一般論として記述すること。最も困難でミッションに重要な技術問題の処理を請け負う技術者の超高度な専門知識へ急速に達するにはどうすればよいか？
- より全体的な問題として、ミッションに重要な活動のほぼ全域に影響が及んでいる電力会社の大半が直面している労働力の高齢化の問題とエキスパートの喪失の問題とを区別すること。労働力の高齢化という難問に対して知識管理とトレーニングを実施しても、重要なエキスパートの喪失による電力ミッションへのリスクを最小限に抑えることはできないといってもよいでしょう。
- 問題に対する研究を完成させるまでのロードマップを確定すること。

キーワード

労働力の高齢化

知識管理

知識保持

目次

1 はじめに 1-1

背景 1-1

目的および趣旨 1-2

方法 1-2

2 高度な専門知識の問題 2-1

電力会社内の専門知識分野 2-1

問題 2-2

アプローチ 2-2

専門用語 2-4

3 文献レビュー 3-1

心理学分野における専門知識の研究 3-1

トレーニングの分野 3-2

教育心理学の分野 3-2

自然主義的意思決定の分野 3-2

知識管理の分野 3-5

教授 3-6

4 電力会社の分野における過去の研究の適用 4-1

電力会社における専門科目の再検討: 専門知識研究の結論との類似 4-1

タイムスケール 4-2

変化する技術への対応 4-2

電力会社における専門科目の再検討: 選択とトレーニング 4-3

5 最終プログラムに向けての初期基準・成功要因 5-1

理論的基礎 5-1

トレーニング要件 5-3

トレーニングは学ぶ対象の近くで実施すること 5-3

トレーニングは柔軟性と適応性を促進すること 5-3

トレーニング資料 5-4

トレーニング手順 5-4

適応性および知覚学習 5-4

推論能力 5-5

フィードバック 5-6

時間圧縮 5-6

意思決定能力 5-8
チームワーク能力および社交術 5-10

6 **ワーキングミーティング 6-1**
ミーティングの理論的根拠 6-1
エキスパートおよびスーパーエキスパートの特性 6-2
エキスパートおよびスーパーエキスパートの特徴の明確化 6-5
組織上の観点 6-8
知識喪失リスク評価 6-9

7 **専門知識習得を急速するためのロードマップ 7-1**
試行および実証 7-1
活動中のスーパーエキスパートとエキスパートのケーススタディの集体成の作成（短期） 7-1
知識管理と専門知識喪失を監督する電力マネージャーの調査（短期） 7-1
スーパーエキスパート候補の選択方法の調査（中期） 7-2
実地調査 7-2
心的動きに係わるタスク分析（短期） 7-2
スーパーエキスパートからの継続的な知識習得（短期） 7-2
困難な事例の採取と分類（中期） 7-3
選択研究（選択方法の調査に基づく）（長期） 7-3
有望なエキスパート候補に対するフィードバックを鋭くする（短期） 7-3
対策後のレビュー 7-3
事前調査 7-3
トレーニングおよび学習 7-4
学習に対するバリアの評価（長期） 7-4
実地訓練（中期） 7-4
結論 7-4

A **参考資料 ..... A−1**

Programa de innovación tecnológica: Optimización de logros en experiencias críticas para la misión

Hoja de ruta de la investigación

1016710

Actualización técnica, diciembre de 2008

Jefe de proyecto de EPRI

D. Ziebell

DESCRIPCIÓN DEL PRODUCTO

El problema de la perdida de conocimiento, es decir, la consecuencia de que los trabajadores se lleven conocimiento no documentado con ellos al dejar su puesto de trabajo, es un tema descrito y analizado en profundidad pero, ¿ha hecho el sector todo lo posible por retener y transferir ese conocimiento no documentado a otros trabajadores?

La investigación desarrollada por EPRI y descrita en este informe indica que la mayor parte del conocimiento no documentado puede transferirse de forma eficaz mediante la formación, el asesoramiento y otros procesos contrastados. Sin embargo, lo que todavía se desconoce es cuánto tiempo tardan los expertos en acumular sus experiencias críticas para la misión y si ese periodo de tiempo puede acortarse. El objetivo de este proyecto es determinar la forma en la que los métodos para optimizar la adquisición de conocimiento y la experiencia pueden desarrollarse para llegar a niveles superiores. ¿Qué encierra el trabajo en si mismo que hace que se tarde tiempo en consolidar? ¿Cuál es la naturaleza cognitiva del trabajo que hace que lograr alcanzar altos niveles de competencia se convierta en una inversión de muchos años?

El análisis que se presenta en este informe muestra lo que se conoce como experiencia adquirida en ámbitos que son a la vez parecidos y distintos a los ámbitos de las empresas.

Resultados y hallazgos

Poco se conoce sobre los tipos de juicios y criterios contrastados que resultan importantes en el ámbito de las empresas por lo que no está claro si los métodos para construir juicios contrastados y documentados en otros ámbitos son transferibles al ámbito de las empresas. Hoy día, los juicios técnicos contrastados en el sector son normalmente el resultado de secuencias específicas y desestructuradas de experiencias que posee un grupo relativamente pequeño de personas, es decir, son el resultado de estar en el sitio adecuado para experimentar correcta y repetidamente sucesos raros que suponen un reto para el personal.

Normalmente, se necesitan 25 años y una inversión de cientos de miles de dólares en sueldos y formación para conseguir lo que consideramos un experto reconocido. Cualquier número de años que se pueda recortar significaría un ahorro y una reducción del riesgo significativos. Una empresa asociada a EPRI estima que la transferencia de conocimiento no documentado de sus expertos a otros ingenieros les puede ayudar a prevenir fallos, con un ahorro estimado de 100.000dólares. EPRI pretende averiguar la forma de reducir el tiempo de obtención de experiencia mediante una regla de tres. El proyecto descrito en este informe también se centra en analizar cómo el personal experimentado del departamento de una empresa podría obtener experiencia en un área distinta en cuestión de un año o dos.

Retos y objetivos

La investigación y teorías presentadas en este informe van a resultar especialmente útiles para el personal de formación y administración responsable de contratar, transferir y educar a las personas que integran las funciones críticas para la misión de las centrales. Los problemas asociados con la pérdida de conocimiento y habilidades sólo se harán más graves si los cambios significativos en las plantillas afectan a un 40-70% del personal, parte del cual se retirará en los próximos 5-10 años.

Aplicaciones, valor y utilización

La hoja de ruta que proporciona este informe recomienda varias acciones encaminadas a uno o más proyectos demostrativos. Entre estas recomendaciones ejecutables, los estudios contribuirán a que temas relacionados con la plantilla de trabajo y la pérdida de conocimiento se discutan en estratos más altos de la empresa, principalmente administración y liderazgo. De esta forma, el debate se desarrollará en unos niveles de detalle incluso mayores que los de los enfoques de evaluación de pérdida de conocimiento que actualmente se emplean. El reconocimiento generalizado de problemas y retos redundará en esfuerzos continuos para crear una cultura del conocimiento. Los estudios de campo y los análisis de tareas cognitivos darán pie a un proceso de adquisición de conocimiento – mostrando el conocimiento, habilidades y estrategias de los expertos en las empresas – de tal forma que dicha experiencia pueda posteriormente utilizarse en formación. Asimismo, los estudios de campo y análisis de tareas cognitivos cristalizarán en materiales que podrán usarse en las iniciativas dirigidas a acelerar la adquisición de experiencia, incluyendo ejercicios más complejos de reducción del tiempo y toma de decisiones.

Perspectiva de EPRI

La contribución de EPRI al conjunto de soluciones a la pérdida de conocimiento se ha centrado en la investigación, desarrollo y prueba de herramientas prácticas de recogida de conocimiento válido no documentado que el personal de las empresas aplicaba para realizar sus tareas y contribuir así al funcionamiento de sus plantas. Un informe del año 2002, *Directrices para recoger conocimiento válido no documentado del personal de las empresas eléctricas* (informe 1004663), desarrolla el alcance del problema y de los métodos de análisis para enfocarlo. El documento *"recogida y utilización de conocimiento de alto valor no documentado en el sector nuclear: directrices y métodos* (informe 1002896), presenta un proceso detallado para aplicar los métodos eficazmente. En "*adquisición y transferencia de conocimiento experto en tiempo real – evaluación de la tecnología y las necesidades*: *hacia métodos automáticos de autoadquisición del conocimiento"* (informe 1009581), el proceso se actualiza y se ofrece una visión adicional que facilita el flujo de determinados tipos de información en poder de los expertos.

Enfoque

En este informe tiene los tres objetivos siguientes:

- Describir el problema a investigar en términos generales. ¿Cómo podemos acelerar la obtención de niveles extraordinarios de experiencia que poseen los expertos encargados de manejar las tareas más difíciles y críticas para la misión asociadas a los aspectos técnicos?
- Diferenciar entre el problema de pérdida de expertos y el envejecimiento de la plantilla, un reto más general que afecta a la mayor parte de las empresas en casi todas las actividades relacionadas con la misión. La formación y gestión del conocimiento que se aplica para la totalidad de la platilla contribuirá en poco, o nada, a minimizar el riesgo de pérdida de experiencia crítica al que se enfrentan las empresas.
- Determinar una hoja de ruta para completar la investigación que permita afrontar el problema.

Palabras clave
Envejecimiento de la plantilla
Gestión del conocimiento
Retención del conocimiento

CONTENIDO

_1_ INTRODUCCIÓN 1-1
Antecedentes 1-1
Objetivo e intención.. 1-2
Método 1-2

_2_ EL PROBLEMA DE LA EXPERIENCIA EXTRAORDINARIA 2-1
Ámbitos de experiencia en las empresas 2-1
El problema.. 2-2
Enfoque.. 2-2
Terminología 2-4

_3_ REVISIÓN DE LA LITERATURA 3-1
Estudios de la experiencia en el campo de la psicología.. 3-1
El campo de la formación.. 3-2
El campo de la psicología educativa.. 3-2
El campo de la toma de decisiones naturalista.. 3-2
El campo de la gestión del conocimiento.. 3-5
Asesoramiento (*Mentoring*).. 3-6

_4_ APLICACIÓN DE LA INVESTIGACIÓN REALIZADA EN ÁMBITOS EMPRESARIALES ... 4-1
Nuevo análisis de las especialidades de las empresas: Similitudes con las conclusiones de los estudios sobre experiencia:.. 4-1
escala de tiempo 4-2
Gestión de la tecnología del cambio 4-2
Nuevo análisis de las especialidades de las empresas: comparación entre selección y formación 4-3

_5_ CRITERIOS INICIALES/FACTORES DE ÉXITO PARA UN PROGRAMA FINAL................ 5-1
Base teórica 5-1
Requisitos de formación.. 5-3
La formación debe minimizar la distancia de transmisión.. 5-3
La formación debe ofrecer flexibilidad y adaptabilidad 5-3
Materiales de formación.. 5-4
Procedimiento de formación 5-4
Adaptabilidad y aprendizaje perceptivo 5-4
Habilidades de razonamiento.. 5-5
Feedback 5-6
Reducción del tiempo.. 5-6
Habilidades para la toma de decisiones 5-8
Habilidades para el trabajo en equipo y habilidades sociales.. 5-10

6 LA REUNIÓN DE TRABAJO 6-1
Lógica de la reunión..6-1
Características de los expertos y los superexpertos..6-2
Definición de las características de los expertos y los superexpertos 6-5
Contexto organizativo 6-8
Evaluación del riesgo de pérdida de conocimiento..6-9

7 HOJA DE RUTA PARA OPTIMIZAR LA ADQUISICIÓN DE CONOCIMIENTO 7-1
Pruebas y demostraciones..7-1
Desarrollo de un corpus para los estudios de casos de expertos y superexpertos (a corto plazo) 7-1
Encuesta a directivos de empresas para tener una visión general de la gestión del conocimiento y de la pérdida de experiencia (corto plazo) 7-1
Análisis de los métodos de selección de los posibles superexpertos (medio plazo) 7-2
Investigación de campo 7-2
Análisis cognitivo de tareas (corto plazo)..7-2
Adquisición continua de conocimiento de los superexpertos (corto plazo)..7-2
Recogida y categorización de casos difíciles (medio plazo)..7-3
Investigación selectiva (basada en el análisis de los métodos de selección) (largo plazo)7-3
Feedback preciso proporcionado a los posibles expertos (corto plazo) 7-3
Revisiones post-acción 7-3
Pre-Mortem 7-3
Formación y aprendizaje..7-4
Análisis de los obstáculos para el aprendizaje (largo plazo)..7-4
Formación en el puesto (medio plazo)..7-4
Conclusión 7-4

A REFERENCIAS.. A-1

Export Control Restrictions

Access to and use of EPRI Intellectual Property is granted with the specific understanding and requirement that responsibility for ensuring full compliance with all applicable U.S. and foreign export laws and regulations is being undertaken by you and your company. This includes an obligation to ensure that any individual receiving access hereunder who is not a U.S. citizen or permanent U.S. resident is permitted access under applicable U.S. and foreign export laws and regulations. In the event you are uncertain whether you or your company may lawfully obtain access to this EPRI Intellectual Property, you acknowledge that it is your obligation to consult with your company's legal counsel to determine whether this access is lawful. Although EPRI may make available on a case-by-case basis an informal assessment of the applicable U.S. export classification for specific EPRI Intellectual Property, you and your company acknowledge that this assessment is solely for informational purposes and not for reliance purposes. You and your company acknowledge that it is still the obligation of you and your company to make your own assessment of the applicable U.S. export classification and ensure compliance accordingly. You and your company understand and acknowledge your obligations to make a prompt report to EPRI and the appropriate authorities regarding any access to or use of EPRI Intellectual Property hereunder that may be in violation of applicable U.S. or foreign export laws or regulations.

The Electric Power Research Institute (EPRI)

The Electric Power Research Institute (EPRI), with major locations in Palo Alto, California; Charlotte, North Carolina; and Knoxville, Tennessee, was established in 1973 as an independent, nonprofit center for public interest energy and environmental research. EPRI brings together members, participants, the Institute's scientists and engineers, and other leading experts to work collaboratively on solutions to the challenges of electric power. These solutions span nearly every area of electricity generation, delivery, and use, including health, safety, and environment. EPRI's members represent over 90% of the electricity generated in the United States. International participation represents nearly 15% of EPRI's total research, development, and demonstration program.

Together…Shaping the Future of Electricity

Printed on recycled paper in the United States of America

1016710

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com