LESSONS LEARNED IN KNOWLEDGE ELICITATION WITH NUCLEAR EXPERTS

Brian M. Moon
Perigean Technologies LLC
725 Jackson Street, Suite 218
Fredericksburg, VA 22401, USA
brian@perigeantechnologies.com

Matthew H. Kelley
Research and Technology Unit
Westinghouse Electric Company
Suite 678 600 Cranberry Woods Drive
Cranberry Township, PA, 16066, USA
kelleymh@westinghouse.com

ABSTRACT (Abstract Head)

The nuclear renaissance has hastened the need for efficient knowledge transfer, from senior experts who brought online and have maintained the earliest generation plants to the next generation of designers and engineers charged with launching the next fleet. While many suggestions for enabling and facilitating this transfer within the course of mentoring and training programs have been proffered, one necessary starting point for any successful transfer program is the acquisition of extensive, highly organized knowledge, expert-level reasoning skills and strategies. The practice of knowledge elicitation provides structured techniques for acquiring expert knowledge, and the most useful of these techniques for conducting knowledge elicitation have been well documented. Less well-documented are the variety of contingencies – i.e., circumstances special to working with senior experts – that can serve to forestall or otherwise challenge the knowledge elicitation process. In this paper, we will outline these contingencies and provide examples of them drawn from our recent experience conducting knowledge elicitation with senior experts from the Westinghouse Electric Company over the course of approximately a year. We will also provide practical advice for mitigating them, or even turning them into opportunities to strengthen the overall acquisition effort.

Key Words: knowledge management, expertise, knowledge elicitation

1   INTRODUCTION

The nuclear renaissance has hastened the need for efficient knowledge transfer, from senior experts who brought online and have maintained the earliest generation plants to the next generation of designers and engineers charged with launching the next fleet. The problem is particularly acute in the nuclear industry where workforce demands have discouraged large-scale, advanced training efforts for many years. Meanwhile, domain technical knowledge has become increasingly specialized, as advances in technology bring new challenges for integrating with analog systems, operational histories reveal unique circumstances, and regulatory affairs introduce new requirements into design, construction and operations. Along with the need to transfer technical knowledge comes the need to transfer experiential knowledge—i.e., the historical and social knowledge that enables efficient execution of mission-critical tasks. Clouding the entire knowledge transfer picture are the security and privacy concerns that cloak the entire industry, concerns that have only become more urgent with time.

These types of knowledge can be bottled up into the notion of expertise. In the nuclear industry, expertise is a must for proficient performance leading to market leadership and mission success. Expertise is the basis for professional intuition—for being able to make good assessments and decisions under stressful conditions. It is based almost exclusively in the accumulation of experience in specific areas of practice. Experts have had many years of *critical* experiences through the application of their skills in the industry. They are critical is nature due to the direct and abundant feedback from the consequences of their actions. Experts make more accurate and reliable judgments and decisions, perform faster, and have richer "mental models" of how their domain functions than novices. They see patterns and anticipate how events will develop. They have developed repertoires for action and rules of thumb for how they expect things to work in a variety of situations.

Many suggestions have been proffered for facilitating the transfer of expertise in the context of the nuclear industry. These include a variety of mentoring and training programs, ranging from one-to-one to the one-to-many transfer. Success of these approaches hinges, first and foremost, on the acquisition of extensive, highly organized knowledge, expert-level reasoning skills and strategies — i.e., expertise. In many cases, these strategies fail because they fail to capture expertise due to its tacit and implicit nature. What experts know is often not encoded anywhere. It is not always apparent, even to the expert, how s/he and what s/he knows. Articulating expertise is often one of an expert's most challenging tasks. If the expert cannot articulate what they know, how can s/he be expected to structure it for transfer?

Many times experts are asked to both develop training materials and content with little or no support. When given tasks of this nature, Experts often have no interest developing materials or have difficultly providing quality materials. They often struggle to manage their time to complete these activities within the current production environment demands.

A robust knowledge transfer effort, then, must facilitate the acquisition of extensive, highly organized knowledge, and the acquisition of expert-level reasoning skills and strategies. The professional practice of "knowledge elicitation" has been developed within and without the industry for just this purpose. Next, we briefly touch on the practice of knowledge elicitation.

2   THE PRACTICE OF KNOWLEDGE ELICITATION

The practice of knowledge elicitation provides structured techniques for acquiring expert knowledge. Hoffman and Moon (2010) presented an overview of these techniques for the American Nuclear Society. They include the diagrammatic technique of Concept Mapping (Moon et al., 2010), which provides a means for eliciting the structure of and relations inherent in expert knowledge, and the Critical Decision Method ("CDM", Crandall et al., 2006), which yields descriptive incident accounts that detail decisions and decision and reasoning strategies. In executing these techniques, knowledge elicitors probe and prompt experts to reveal the elements of their expertise. Prompts include the following, and serve to dig deep into the experts experience and knowledge bases.

-The Past & Future probe attempts to identify examples of when experts have been able to recognize how a situation developed and anticipate its outcome.

-Experts are able to detect cues and see patterns that less experienced people might miss. The Big Picture probe is used to identify the important elements that an expert tracks to generate the big picture of the situation.

-The Noticing probe is applied to elicit examples of an expert's ability to detect cues and patterns.

-The Job Smart probe is used to obtain examples of how experts maximize efficiency on the job.

-Experts are able to improvise and adapt to capitalize on opportunities. The probe, Opportunities/Improvising, was developed to obtain information about this element of expertise.

-The Self Monitoring probe has been used to capture examples about how experts monitor their own performance and take corrective action based on this self-assessment.

-The Anomalies probe attempts to uncover examples of instances when experts detected deviations from the norm or noticed situations when an expected event did not occur. The ability to detect anomalies is an element of expertise.

-Technology can sometimes provide unreliable or misleading information to the user and experts can often recognize when a system is behaving this way. Elicitors can use the probe Equipment Difficulties to elicit examples of when the participant noticed when their equipment was providing misleading information.

Use of these techniques is the domain of professional knowledge elicitors. The knowledge elicitation industry has documented much guidance for efficient and effective use. Less well-documented, however, are the variety of contingencies – i.e., circumstances special to working with senior experts – that can serve to forestall or otherwise challenge the deployment of a knowledge elicitation process. In the remainder of the paper, we outline these contingencies and provide examples of them drawn from our recent experience conducting knowledge elicitation with senior experts from the Westinghouse Electric Company ("Westinghouse") over the course of approximately a year. We also provide practical advice for mitigating them, or even turning them into opportunities to strengthen the overall acquisition effort.

3   LESSONS LEARNED

Since 2008, Westinghouse has been developing a robust knowledge transfer program. It includes the use of knowledge elicitation for capturing and structuring expert knowledge. Deployment of knowledge elicitation with senior experts has enabled discovery of a variety of contingencies. By contingencies, we mean aspects of knowledge elicitation that may occur, and thus must be prepared for. Our list of contingencies includes: Expert Preferences, Expert Availability, Scoping, and Production. To be clear, with this list we are outlining contingencies that stem from working with senior experts. Indeed, there are many contingencies that can arise in the deployment of a knowledge elicitation program stemming from other sources, for example, leadership, information technology and acquisition. Our list concentrates on the set that are unique to working with senior experts.

3.1 Contingency : Expert Preferences

All of the knowledge elicitation techniques described above were successfully employed with senior experts. However, not every method worked the same for everyone. Indeed, expert comfort and interest in a particular method as well as the expert's communication style often dictated method success. For example, several experts in our program gravitated toward the Concept Mapping. They were engaged in the process of building the Concept Maps and at times even directed Concept Map construction. These experts would often use the Concept Maps to organize their thoughts and guide the discussion with little prompting from the elicitors.

We decided early in working with one expert, however, to avoid Concept Mapping. It became apparent in early sessions that the expert was much more comfortable preparing outlines for the sessions, based on the structure of knowledge he kept in his head. Also, this expert not a native English speaker; thus, the very act of conversation was fraught with challenges in understanding. The notion of requiring this expert to concentrate on the task of creating Concept Maps seemed daunting. Rather than force the expert to yield to our approach, we allowed him to structure the sessions and prompted him to deepen in areas where we spotted his expertise—i.e., areas that suggested tacit knowledge, judgments, and historic perspective.

For another expert, other diagrams proved valuable in structuring elicitation. This expert was valued for his encyclopedic knowledge of plant systems, and the unique, historical aspects of each system at

each nuclear plant he had been affiliated with. The most useful diagrams for enabling knowledge elicitation were high-level system description diagrams. We used these diagrams to structure elicitation, and prompted the expert to recall unique aspects using the probes noted above.

Still other experts were much more interested in and able to discuss incidents from their vast experience and the lessons learned from these events. For these experts, CDM was the most comfortable technique, and thus the most effective method for eliciting knowledge and structuring the sessions.

3.1.1   Mitigation and Opportunity

Throughout our knowledge elicitation sessions, we remained flexible, and ready to quickly adapt our approach to a particular expert's interest, comfort and communication style, yet kept expertise as the focus of every session. Having a solid grasp on the varieties of knowledge elicitation techniques, their strengths and weaknesses, and a keen eye for anticipating the direction that an expert wants to take a session were key to our success.   Increases in expert interest and comfort led to increased expert engagement and significant improvements in the quality of the sessions.

Indeed, it is fair to say that most of the Westinghouse personnel that were involved in or witnessed our knowledge elicitation sessions came away from them with a palpable sense of the expertise involved in and benefits gained from professional knowledge elicitation. Most were highly impressed with the volume and depth of knowledge that we captured, as well as the immediacy of the structure we could develop with Concept Maps.

Most importantly, for the experts involved in the sessions, their explicit statement of the realized benefits of each knowledge elicitation provided a foothold for us to reach for greater success. In one case, one of our experts served to demonstrate Concept Mapping for a business unit considering wider deployment of the technique. That unit expressed even greater interest after seeing the demonstration and hearing the perspective of the expert. As the voices of the organization, their interest in the techniques was important in getting others to participate. This was important because, as our next contingency suggests, participation was not always a given.

3.2 Contingency : Expert Availability

Given the need for rich detail, and the scope of knowledge any expert will possess, knowledge elicitation was typically not a one-time affair. Indeed, it is always best to think of knowledge elicitation "sessions," over the course of which expertise is elicited, structured, reviewed and revised with varying levels of participation from the experts. Yet, almost by definition, experts never have enough time to engage in knowledge elicitation. Their expertise makes them the "go-to" people in the organization. Their deep experience is called upon daily for routine and non-routine tasking, ensuring efficiency and guaranteeing that customers remain customers.

Thus, knowledge elicitation was constantly under time pressure. Our ideal sessions lasted three to four hours, during which we could begin to cover a topic in depth or start to build the landscape of an expert's knowledge base. It was also ideal to hold consecutive sessions over the course of two days. This enabled the expert to concentrate on the topic at hand and revisit details for clarification as they continued to think it over between sessions.

But finding time for one session, let alone two, was always a challenge. The operational tempo for most of our experts was exceedingly high. On occasion, operations interrupted ongoing sessions, requiring the expert's attention during a scheduled session. At times, operational requirements took the expert out of the loop of the knowledge elicitation project, for weeks and even months at a time. The range of time for completion of the scheduled knowledge elicitation sessions (30 to 40 hours) was between three to seven months.

3.2.1 Mitigation and Opportunity

Mitigation in this area became critical as this was the most significant barrier to successful completion of each effort. Tactical methods of mitigation techniques can be used such as:

1. Flexibility of session times to the experts' schedules. This included coordinating travel schedules to meet experts where they had time to participate.

2. Mapping out and scheduling the sessions early in the process. Thus, giving the expert a reasonable time horizon such that they can tangibility sees the end of their time commitment.

Besides the implementation of these tactical methods, the most effective mitigation stemmed from the level of engagement with the expert – that is, the "meta-task" of doing knowledge elicitation. Even though experts have significant workloads, because the experts were thinking about how they worked and reflecting on matters of importance to them, they demonstrate amplified willingness to make schedule adjustments or even work additional hours to allot time for knowledge elicitation sessions. Even though we might expect to struggle with the engagement of busy experts, our experience was quite the opposite. All of our experts repeatedly commented on the value and usefulness of the knowledge elicitation efforts. Many experienced personal benefits from it. The experts we worked with are leaders in their field and are often responsible for educating and training others. The knowledge elicitation helped them organize their thoughts and materials for other uses (e.g., mentoring, teaching, and training), assisted with mentoring duties (e.g., by either having mentees in the room or material for mentees offline). In one case, an expert saw the knowledge elicitation as an opportunity to craft the story of his career and involvement in the evolution of key industry technologies. In several cases, the experts noted an intention to use the content captured during a knowledge elicitation session in the development of training materials.

We found that our elicitation methods were able to uncover much of their expert tacit knowledge, and heard many variations of "I've never thought about it that way, but now that I've said it…", which were often followed by a new insight. In other instances, the experts noted that the elicitation sessions revealed specific new technical insights that the experts thought should be included in Westinghouse technology evolutions. In all cases, the experts found value in articulating what they knew, guided by the prompting and overall organization of the sessions.

The opportunity here lied in the evidence that several of the experts promoted the project to their peers, subordinates and superiors. As more personnel become aware of the value and benefits of knowledge elicitation, the program can find new ways to succeed. We will continue to develop this opportunity by looking for ways to integrate knowledge elicitation into routine patterns of work. As our program has expanded, we have sought connections with other knowledge management and corporate training efforts so that knowledge elicitation is seen as an integral aspect of knowledge transfer, instead of yet another task. Related to this goal is the contingency of scoping the knowledge elicitation effort with each expert.

3.3 Contingency : Scoping

We learned early in the project the importance of managing the scope of each expert's knowledge elicitation. The experts had a tremendous amount of knowledge and experience on various topics, and in most cases we were introduced to the expert with only broad knowledge areas to focus on – e.g., "instrumentation and controls" or "fuels." These broad scoping instructions were no doubt due to the incipient understanding of knowledge elicitation held by the sponsors of the experts – i.e., the supervisors who nominated them (and sponsored their time) to participate. There was a general sense the knowledge transfer was necessary, and that knowledge elicitation should be a key piece of the solution.

But there is a big difference between saying "we're going to capture your knowledge" and "we're going to capture your knowledge about X." The former statement rightly draws skeptical looks from all

parties, and as a starting point is only useful for mapping out the landscape of the expert's experience and knowledge base. While this is certainly a valuable exercise in and of itself, it can also be quite time consuming.

The latter statement is a much more efficient route to expertise. It enables the expert to focus on a specific aspect of their expertise, and provides the best entry point for introduction of knowledge elicitation techniques. Indeed, both Concept Mapping and CDM are intended to start with a Focus Question or specific incident.

But getting to the latter statement takes effort and, more importantly, involvement beyond the expert and knowledge elicitor. At the least, it requires involvement of the expert's sponsor/supervisor, to suggest topics with as much specificity as possible. Even better, it would involve engagement from personnel responsible for business development and forecasting. Most knowledge elicitation is, for the most part, a retrospective activity (though some techniques enable projection and support the development of anticipatory thinking). What is being captured is the expert's knowledge about the past—not all of which will be important to the organization in the future. Thus, scoping should ideally include those charged with moving the organization into the future and looking out for the broader business interests. This class of people may or may not include the experts, but it likely will not include the knowledge elicitors.

Because in most cases we only receive broad guidance on knowledge topics, we spent many hours exploring the breadth of our experts' expertise. These were hours well spent, particularly for developing rapport with our experts and for identifying cross-connections between knowledge topics across our experts. But given our prior contingency, the best use of the experts' valuable time was to capture the depth of their knowledge. In many cases we achieved this, but we could have achieved more with focus.

3.3.1   Mitigation and Opportunity

We learned that providing the sponsor with information about the elicited content early in the process enabled them to more effectively shape the scope of the remaining elicitations. We found that providing the sponsor with early drafts of a "Knowledge Map" was a useful format for sharing this knowledge. A Knowledge Map is a simplified Concept Map that included the high-level topics we had explored with the experts, arranged in a hierarchy. Providing these to the sponsors helped them help us to know where to dive deeply.

We also encouraged continuous dialogue between the knowledge transfer stakeholders – i.e., the experts, their sponsors, peer-level and junior colleagues to whom knowledge was to be transferred, and our elicitors. Dialogue was mostly informal, but punctuated by formalizations in our project plan, which included peer-review of content and an evaluation of our knowledge management system. More formalization of these processes will make for a beneficial mitigation strategy in the future. The constraint on the strategy, however, will be the next contingency.

3.4 Contingency : Production

In order to initiate the knowledge transfer process, the content of knowledge elicitation must be produced, preferably in a highly-organized, easily digestible and explorable format. Most importantly, it must be verified.

We realized early in the project that expert review of our initial drafts was an important step in the production process. Much of the knowledge elicited from the experts was highly technical and despite our best efforts to organize domain knowledge and seek clarification during the sessions, there was still the potential for error. Experts needed to review all of our products.

However, we also discovered a correlation between the volume of content we developed and the feasibility of this approach – that is, the more content that is available, the less feasible is this approach. Moreover, several experts preferred to review content outside the context of the sessions. While this

approach resulted in most cases in highly refined products, we also discovered a severe trade-off in efficiency of the approach, as several experts' schedules precluded them from conducting the reviews in a timely fashion.

Another phenomenon exacerbated the time-pressure contingency. In many cases, as the experts reviewed the content we had elicited, they experienced the opportunity of reviewing their own words. For most people, this is always an eye-opening experience, for better and worse. At worst, the experts realized that their intended meaning had either been lost in translation, or was best understood with context that was missing. At best, the experts realized that "topic X" should lead to a discussion of "topic Y, Z, A, B… etc." In these cases, the expert extended content far beyond what we had initially captured. They were supplying additional explanation, creation of original diagrams and other material, and providing us with documentation that could be linked to or integrated with what we had captured. This was highly beneficial for improving the overall quality of our knowledge elicitation products, but further delayed their production.

We also needed the peers of our experts to review our documents to ensure that knowledge was accurately represented. This, of course, required additional resources and coordination.

3.4.1   Mitigation or Opportunity

Our primary mitigation strategy was to send the experts electronic copies of our draft documents to review between sessions. This plan, however, was constrained by the time-pressure contingency. Because the experts had extremely busy schedules and often could not devote additional time to review the documents, our initial drafts were significantly delayed as we developed our internal production process. In some cases, the delay was extremely long, upwards of six months.

As we reached concluding sessions with some of our experts, we adopted the approach of conducting the reviews during the sessions. Working face-to-face with the experts improved the quality of the review process. Direct interaction with the experts allowed the elicitors and expert to discuss potential changes and experts could clarify their written feedback with verbal explanations. These sessions were made even more efficient and effective when the elicitors relied on the completed "Knowledge Map" to help the expert understand the organization of the content. This approach helped to ensure that changes to the documentation were implemented correctly and additional knowledge was elicited if necessary. It was hampered, however, by the sheer volume of content for some experts.

Our future knowledge elicitation efforts will consider the review process early and often, and continuously gauge which approach may provide most efficient, and remain flexible in execution.

We also intend to increase the engagement level of peers and junior colleagues. These stakeholders will enable verification and expansion of the content, while simultaneously helping to achieve the goal of knowledge transfer.

4   CONCLUSIONS

Acknowledgement of problem areas and implementation of the contingency approaches can have a significant impact on a knowledge elicitation and ultimately a knowledge transfer process. Constant adjustments and increased process flexibility are essential to effectively respond to these critical problem areas. Integration of mitigation methods can significantly improve knowledge elicitation programs as well as aid the expert development of protégés.

It should become clear that these contingencies are highly-dependent on each other. As one surfaces, it often places additional pressure on the others. Indeed, as we developed our mitigation strategies and capitalized on opportunities, we were forced to consider how these might inadvertently aggravate other contingencies. Thus, our primary point in proffering these lessons learned is to enable proponents and

providers of knowledge elicitation programs to consider them in advance, and craft their programs accordingly.

5   ACKNOWLEDGMENTS

6   REFERENCES

1. R. R. Hoffman & B. M. Moon, "Knowledge Capture for the Utilities," *Seventh American Nuclear Society International Topical Meeting on Nuclear Plant Instrumentation, Control and Human-Machine Interface Technologies NPIC&HMIT 2010, Las Vegas, Nevada, November 7-11, 2010, on CD-ROM, American Nuclear Society, LaGrange Park, IL (2010)*

2. B. M. Moon, R.R. Hoffman, J.D. Novak & A. J. Cañas (Eds.) *Applied Concept Mapping*, Boca Raton, FL: Taylor & Francis (2010).

3. B. Crandall, G. Klein, & R.R Hoffman, *Working Minds: A Practitioner's Guide to Cognitive Task Analysis,* Cambridge, MA: MIT Press. (2006).