Transforming Knowledge: Capturing Engineers' Cognitive Expertise

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ABSTRACT

Introduction: This paper reports the initial stages of an on-going project with leading engineering experts working with the manufacture of petroleum additives. The project aims to provide transformative, effective methodological solutions to Knowledge Management transfer. **Method:** Engineering experts are being trained to use Applied Cognitive Task Analysis (ACTA) techniques in order to document the cognition of their expert peers. **Results and discussion:** Results to date have had high face validity and otherwise undocumented knowledge has been elicited. A key challenge here is to ensure the practitioners' capture cognition and continue to provide transformative innovations, and continuous knowledge transfer within this highly intelligent workforce.

KEYWORDS

Applied cognitive task analysis, engineering, expertise, situation-assessment, scenario planning

INTRODUCTION

Capturing, documenting and utilising professional cognitive expertise where technological excellence is fundamental to success is a critical challenge for global organisations. To date the naturalistic decision making (NDM) community and related communities of practice have successfully reported the merits of ACTA and associated CTA techniques (Hoffman & Militello, 2008; Militello, Wong, Kirschenbaum & Patterson, 2011). More recently these techniques have also begun to appear in other research areas of organisational behaviour and management practice (Gore and McAndrew, 2009; McAndrew & Gore, 2012; Osland, 2010) however, reports which focus upon the training of practitioners to adopt such techniques is less well documented. This work therefore also examines the importance of the role of academics translating methodological research developments for explorations *of* and *in* professional knowledge management practice (Anderson, 2007).

The researcher was asked to explore (within a much wider organisational project on knowledge management) how best expert cognition in engineering expertise could be elicited, documented and utilised. This poster shares the process of training transfer and the illustrative results of a practitioner CTA. The expert cognition associated with managing uncertainty is highlighted (Lipshitz & Strauss, 1997) and aspects of hot/sensory based cognition explored.

The task illustrated here is from an expert process engineers analysis of the key cognitive demands involved in the task of completing an "initial manufacturing plant trial start-up". When new petroleum additives are developed, teams of research engineers with professional expertise in chemistry and physics run pilot or 'start up' trials within the manufacturing plant. This process has a high degree of risk associated with it and can be expensive and time-consuming, in terms of both health and safety and continued product innovation success. Process and product development are also subject to unique legal confidentiality agreements in this area of engineering. The task of setting up and monitoring a plant trial therefore involves a high degree of macro-cognitive complexity within a NDM type framework (Orasanu & Connolly, 1993). The macro-cognitive complexity i.e. "the cognitive adaptation to complexity" (Klein, et al 2003; Klein & Hoffman, 2008) can involve several experts managing risk and uncertainty, making sense of their dynamic environment, with high stakes and shifting, ill-defined goals under time-pressured situations.

METHOD

A one day (7 hour) briefing about the use of ACTA techniques was provided for a small group of professionals with different areas of engineering expertise. The cognitive areas ACTA and CTA seek to address are: difficult judgments and decisions; attentional demands; critical cues and problem-solving strategies. During a second day the researcher trained 3 engineers to use a selection of the ACTA techniques (Militello and Hutton, 1998 recommend that three to five subject matter experts usually exhaust the domain of analysis).

First, the researcher completed a task diagram and knowledge audit in order to illustrate the interview techniques associated with stage one and two of ACTA. This process was stopped and re-started in order for the engineers

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to ask questions and clarify the process. The first stage of ACTA a production of a *task diagram*, provides the interviewer with a broad overview of the task. This interview helps identify areas requiring complex cognitive skills which can be examined in depth in stage 2 of the process: *the knowledge audit*. In order to identify the type of tasks which were seen to be essential by the expert engineers, task diagrams were completed for key areas of engineering work which involved cognitive complexity. It is this type of work the organisation recognised was not currently documented meaningfully in training procedures. The professionals involved in the knowledge management project were mindful that areas of expert cognition were not being transferred to novice engineers.

Second, the engineers practiced knowledge audit techniques with each other and documented their understanding of complex cognition. Again, a stop – start approach was adopted to facilitate the question technique and the documentation of knowledge elicited. *The knowledge audit* focuses upon a cognitive sub-task elicited from the task diagram and is well documented in the research literature in expert-novice differences (Crandall et al, 2006). Table 1 illustrates key questions and probes.

An optional third stage, *the simulation interview* assists the understanding of participants' cognition within the context of a challenging scenario. This can be useful for developing training recommendations and is an area of ongoing work with the organisation. Finally, a cognitive demands table was completed by the engineers, providing an analytical summary of data elicited.

Table 1: Knowledge Audit probes.

1. **Past and future** : Experts know how the situation developed and know where the situation is going (de Groot 1946/1978; Endsley, 1995; Klein & Crandall, 1995; Klein & Hoffman, 1993): Is there a time when you walked into the middle of a situation and knew exactly how things got there and where they were headed?

2. **Big picture**: Experts understand the whole situation and understand how elements fit together (Endsley, 1995; Klein, 1997): Can you give me an example of the big picture for this task? What are the major elements you have to know and keep track of?

3. **Noticing**: Experts can detect cues and see meaningful patterns (de Groot, 1946/1978; Klein & Hoffman, 1993; Shanteau, 1985): Have you had experiences where part of a situation just 'popped' out at you; where you noticed things going on that others did not catch? What is an example?

4. **Tricks of the trade/Job smarts**: Experts can combine procedures and do not waste time and resources (Gore, 2004; Klein & Hoffman, 1993): When you do this task, are there ways of working smart or accomplishing more with less i.e. tricks of the trade – that you have found particularly useful?

5. **Improvising / opportunities** : Experts can see beyond standard operating procedures and take advantage of opportunities (Dreyfus & Dreyfus, 1986; Shanteau, 1985): Can you think of an example when you have improvise in this task or noticed an opportunity to do something better?

6. **Self-monitoring** : Experts are aware of their own performance and notice when performance is not what it should be and adjust to get the job done (Cohen, Freeman & Wolf, 1996; Glaser & Chi, 1988): Can you think of a time when you realized that you would need to change the way you were performing in order to get a job done?

7. **Anomalies**: Experts can spot the unusual and detect deviations from the norm (Klein, 1989; Klein, 1997; Klein & Hoffman, 1993): Can you describe an instance where you spotted a deviation from the norm, or knew something was amiss?

8. **Equipment difficulties**: Experts know equipment can mislead and do not implicitly trust equipment as novices might (Cannon-Bowers, Salas & Converse, 1993): Have there been times when the equipment pointed in one direction, but your own judgment told you to do something else? Or when you had to rely on experience to avoid being led astray by the equipment?

Adapted from Militello & Hutton (1998)

RESULTS

At first the engineers found the process of interviewing and being interviewed using the CTA techniques a little challenging. They quickly however, became very comfortable using the knowledge audit probes and found the structured approach very rewarding. Each of the engineers reported that the knowledge elicited, including key cues for improving situation awareness and scenario planning had rarely been documented in such a pragmatic way previously. The results of an independently completed cognitive demands table completed by the experienced CTA researcher was comparable to the engineers' interpretations (See Table 2). Here we see clear areas of cognitive complexity for the expert plant trial engineers: *effective communication*; *planning ahead* (responding to action-feedback loops); and *noting key technical cues and strategies*. By eliciting the macro-cognitive processes involved in this challenging task, the experts have noted why these three areas can be difficult (especially for novices), this includes time-pressure, using insightful information rather drowning in data (the engineers can request many reports to check the development of the new petroleum substance and be easily overloaded); and assessing the situation in order to be flexible. The engineers then go onto make explicit suggestions about how to improve and sharpen the cognition required to complete a successful trial, for example always over sample progress reports and recognise there is no need to analyse all of them under time-pressure.

In addition, an important feature which emerged to the surprise of the engineers was the importance of hot/sensory based cognition. Documenting cues associated with emotions and sensory based cognition with specific tasks may then lead to improvements in situation awareness, especially concerning hazards and potential errors in the manufacturing process. For example several engineers described noticing peculiar smells at 2 am in the morning which resulted in adjusting the manufacturing process before the new petroleum additive was destroyed, making significant economic savings and avoiding potential hazards.

Table 2. Illustrative Cognitive Demands Table

For Plant Trials/Start Up

Difficult Cognitive Element	Why difficult?	Common errors	Cues & strategies used
Effective communication	• Maximising information sources requires effort and maintenance • Sorting important information from nice-to-have • Possible language barrier	• Excessive focus on one direct contact • Neglecting applications engineers	• Get involved in operator training • Get out and about, talk to operators and analytical chemists • Regular e mail summary update to customers/interested parties
Planning ahead / sticking to plan	• Time consuming & tedious • Misplaced fear of corrective feedback to published plan • Concern about "planning for failure • Plant may want to complete trial to return to regular production	• Inadequate plan • Fail to document possibility of unexpected events • Tendency to panic when faced with a "surprise" • Inadequate sampling schedule • Not knowing when to be flexible	• Publish and agree in advance • Include "what if" scenarios and plan for off spec product • "Phone a friend" – use all available resources, collaboration • Over sample, no need to analyse all of them • Send some samples to own lab • Apply full testing schedule to 1st batch, be flexible later if appropriate
Technicals • Compare plant samples with lab programme • Test Property trend • hallenge analytical data • DCS constraints • Commissioning	• Too much control room time • Separating important data • Embarrassment factor • Believe briefing	• Don't visit unit/lab • Neglect logical analysis • Only look at numbers, not the samples • Underestimate complexity and risk • Wrong rotation direction	• Get out of the control room • Plot or tabulate data • Diplomacy • Get face to face contact • Ask to meet • Be present for the commissioning testing

CONCLUSION

Whilst this work is on-going it aims to be original in its application as few studies document such applied innovation including practitioners with the co-construction of knowledge. The elicited scenarios will aim to assist novice engineering professionals raise their situation awareness in relation to specific tasks, with areas of cognitive complexity being clearly defined in an organisational based repository of training scenarios. Further, more detailed work is currently being completed in this area which should support knowledge management development within the organisation. In addition, further work needs to be completed to assess if all of the professional engineers can easily utilise the ACTA techniques, assisting organisational learning in order to provide transformative innovations to knowledge management and support macro-cognitive awareness.

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REFERENCES

Anderson, N. (2007). The practitioner-research divide re-visited: strategic-level bridges and the role of IWO psychologists. *Journal of Occupational and Organizational Psychology*. 80, 2,175-183.

Gore, J. & McAndrew, C. (2009). Accessing expert cognition, *The Psychologist*, 22, 3, 218-219.

Hoffman, R.R., & Militello, L.G. (2008). *Perspectives on cognitive task analysis: Historical origins and modern communities of practice*. New York, NY: Taylor & Francis.

Klein, G., Ross. K.G., Moon, B.M., Klein.D.E., Hoffman, R.R., Hollnagel. E. (2003). Macrocognition. *IEEE Intelligent Systems*, 18, 3, 81-85.

Klein, G., & Hoffman, R. (2008). Macrocognition, mental models, and cognitive task analysis methodology. In J. M. Schraagen, L. Militello, T. Ormerod, & R. Lipshitz, (Eds.). *Naturalistic decision making and macrocognition.* (pp. 57-80). Ashgate: Hampshire, U.K.

Lipshitz, R. and O. Strauss (1997). Coping with Uncertainty: A Naturalistic Decision-Making Analysis. *Organizational Behavior and Human Decision Processes,* 69, 2,149-163

McAndrew, C. & Gore, J. (2012). Understanding preferences in experience-based choice: a study of cognition in the wild. *Journal of Cognitive Engineering and Decision Making*, on line in advance.

McAndrew, C. & Gore, J. (2010). "Convince Me..." An Inter-Disciplinary Study of NDM and Portfolio Managers. In Mosier, K.L. & Fischer, U.M. (Eds.) *Informed by Knowledge: Expert Performance in Complex Situations.* Psychologist Press , 353-369.

Militello, L.G. & Hutton, R.J.B. (1998). Applied cognitive task analysis (ACTA): A practitioner's toolkit for

understanding cognitive task demands, *Ergonomics*, 41, 11, 1618-1641.

Militello, L.G., Wong, W., Kirsechenbaum, S.K., and Patterson, E. (2010). Systematizing discovery in cognitive task analysis. In Mosier, K.L. & Fischer, U.M. (Eds.) *Informed by knowledge: Expert performance in complex situations*: 23-40. New York, NY: Taylor and Francis.

Orasanu, J. & Connolly, T. (1993). The reinvention of decision-making. In: G.A. Klein, J. Orasanu, R. Calderwood & C.E. Zsambok (Eds.), *Decision making in Action: Models and methods:*3-20. Ablex, Norwood, NJ.

Osland, J. S. (2010). Expert cognition and sense-making in the global organization leadership context: A case study. In Mosier, K.L. & Fischer, U.M. (Eds.) *Informed by knowledge: Expert performance in complex situations*: 23-40. New York, NY: Taylor and Francis.

Schraagen, J.M.C., Militello, L., Ormerod, T., & Lipshitz, R. (2008) (Eds), *Naturalistic decision making and macrocognition*. Aldershot, UK: Ashgate Publishing Limited.