Advancing ACTA: Developing Socio-Cognitive Competence/Insight

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ABSTRACT

Accelerating the cognitive expertise of engineering professionals is a critical challenge for many high reliability, international organizations. This paper reports a collaborative, longitudinal, academic practitioner project which aimed to elicit, document and accelerate the cognitive expertise of engineering professional working with the manufacture and management of petroleum additives. 25 engineering experts were trained by three academic psychologists to use applied cognitive task analysis (ACTA) interview techniques in order to document the cognition of their expert peers. Results had high face validity for practitioners who elicited hot/sensory based cognition, a number of perceptual skills and mental models, highlighting undocumented context specific expertise. We conclude from a peer review of findings combined with experienced CTA analysts that ACTA techniques can be advanced in context by the explicit recognition and development of socio-cognitive competence /insight.

KEYWORDS

Applied cognitive task analysis, engineering, expertise, socio-cognitive competence/ insight.

INTRODUCTION

To date the naturalistic decision making (NDM) community have reported the strengths of applied cognitive task analysis (ACTA) and associated cognitive task analysis (CTA) techniques (Hoffman & Militello, 2008; Roth, 2008; Militello, Wong, Kirschenbaum & Patterson, 2011) which aim to capture and translate tacit cognition, developing new and important insights about how people are completing tasks. More recently these techniques have also begun to steadily grow in other research areas of organisational behaviour and management practice (Gore and McAndrew, 2009; McAndrew and Gore, 2012; Osland, 2010, 2013). Reports which focus upon the training of practitioners to adopt such methods and techniques however are less well documented. This work continues to examine the importance of the role of academics translating methodological research developments for impact and explorations *of* and *in* professional knowledge management practice (Anderson, 2007). In addition, we aimed to ensure that aspects of cognitive expertise that are difficult to articulate were documented with clear application validity.

Organizational Context

Infineum, (a joint venture between ExxonMobil and Shell), the participants' workplace, is a leading organization in the formulation, manufacture and marketing of petroleum additives for lubricants and fuels. Shell has a long history of innovation in decision making and has effectively used scenario planning (Wack, 1985) for more than 45 years (see Wilkinson & Kupers, 2013 for a recent review). Shell's scenario practice began by exposing and questioning the future and facilitated dialogue in which managers' assumptions could safely be shared, questioned and challenged. Many business units and different organisational functions besides strategy and finance went on to develop scenarios which focussed upon the big-picture. In the 1980s however, a refocus was required which concentrated on '*deep listening'* in order to uncover uncertainties, probing the core concerns of leaders. Scenarios have continued to evolve and Shells' scenario developers aim to keep scenarios relevant and challenging learning tools which have impact upon organizational thinking and cognition.

Set within this innovative organisational culture the authors' were invited to explore within a much wider organisational project on knowledge management, *how best expert cognition in engineering expertise could be elicited, documented and shared, aiming to provide knowledge which would accelerate novice engineers' complex cognitive decision making processes.* Whilst Shells scenarios are most often at a macro-level of analysis this case organization was concerned with capturing expertise at the level of the individual. A key challenge here was to ensure the practitioners' accurately captured cognition in order to maintain continuous knowledge transfer within this highly qualified workforce. This paper documents the process of training transfer. Expert cognition associated with managing uncertainty is highlighted (Lipshitz & Strauss, 1997) and aspects of hot/sensory based cognition explored. Notably, we offer suggestions for adapting and improving the CTA methods for management practitioners and highlight the importance of developing socio-cognitive competence. This latter area as yet, has been unexplored within the NDM or management community of researchers in depth and echoes Hoffman (2014) call for further explorations of the social aspects of CTA. We also note the importance of translating the findings from CTA for knowledge management, future scenario planning, management learning development and echo a cognitive constructionist approach.

Applied Cognitive Task Analysis: unpacking expertise

Researchers have commented on the nature of expertise for several decades, significantly, Chi et al, (1988); Ericsson & Smith, (1991); Feltovich, Ford & Hoffman, (1994) within both laboratory-based examination and naturalistic investigation, exemplified by the Naturalistic Decision Making (NDM) framework. It is also important to note that this body of research has highlighted that experts learn in four key ways (Koehler & Harvey, 2004):

1. engaging in deliberate practice, often setting goals and criteria for evaluation;
2. compiling extensive experience banks;
3. obtaining feedback that is accurate, and timely; and
4. enriching their experiences by reflecting on their experience and lessons learnt from mistakes.

Several categories of knowledge related to expertise discriminate experts from other by describing what experts know and others, including novices, do not. Declarative and procedural knowledge (Anderson, 1983) are more apparent in experts. Put simply, experts know more domain and task related facts. In addition researchers within the NDM community suggest that: strong perceptual skills (Klein and Hoffman, 1983) are an essential component of expertise in many settings, as are mental models with depth; sensemaking of associations; the ability to run mental simulations; richer mental models enable experts to quickly spot anomalies and problems and also formulate information seeking tactics to manage uncertainty. Alongside the above components NDM research in the field suggests that experts metacognitive processes ensure that they take into account their own individual strengths and limitations. (For a recent discussion about how to recognise "good" CTA –see Roth et al 2014)

METHOD

Stage one: A pilot one day (7 hour) briefing about the use of ACTA techniques was provided (Gore, 2013) for a small group of professionals with different areas of engineering expertise. During a second day one of the authors trained 3 engineers to use a selection of the ACTA techniques (Militello and Hutton, 1998).
Stage two: a 3 day longitudinal (twenty one hours) training event completed over 3 months was provided by the 3 authors/CTA instructors for 22 engineering professionals (5 female, 17 male). The professionals had a range of engineering expertise in management, manufacturing technology, finance, human resources, information technology, product development and operations management. Many of the participants were senior research scientists educated to doctoral level, all with 5-15 years of domain specific experience (classified here, as domain experts).

Procedure

First, the researchers' 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 to ask questions and clarify the process. The first stage of ACTA the 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 (experts) involved in the knowledge management project were mindful that areas of expert cognition which would be elicited via ACTA would result in more explicitly documented knowledge, which would be ultimately transferred to novice engineers for training purposes. The interviewee (practitioner engineer) begins by asking the interviewee (expert engineer) to break down a cognitive task related to their expert job role into 3 to 6 steps. These steps/stages are documented via a flip chart/ cognitive map which show 3-6 circles which relate to the task. The interviewer then asks which step/stage of the task is most cognitively challenging and why may novices find this difficult. This first stage can take up to 30 minutes to complete. The interviewer is encouraged to check on understanding with the expert to ensure that she or he agrees that the task diagram accurately provides a broad overview of the task. Together the interviewer and interviewee identify which element of the task is most cognitively complex and takes most thinking, judgment and decision making. This stage of the task is then explored and probed in great detail by completing stage two of ACTA, the Knowledge audit.

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). A series of well-developed questions which are based on extensive research on expert thinking form the focus of the knowledge audit (Militello & Hutton, 1998). This stage of the ACTA is iterative and can take up to two hours to complete, eliciting lived stories and scenarios from the experts being interviewed.
An optional third stage, *the simulation interview* assists the understanding of participants' cognition within the context of a challenging scenario developed from the knowledge audit. Simulations may be paper based or computer-based exercises which can then be a given to several domain experts to explore macro-cognitive complexity. 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. The cognitive demands table is a useful summary which provides an analysis of key aspects of expert cognition within the domain context and also clearly illustrates which aspects novices may find difficult. By documenting difficulties and capturing key cues and strategies for success, tacit knowledge is clearly illustrated.
In addition to providing training in the ACTA techniques we also provided a briefing about theoretical issues in decision making and an exercise to facilitate active listening and questioning skills, as most of the participants had not previously had experience of research-based interviewing and had a genuine interest in the theoretical roots of the CTA methods. All participants had no prior experience of intensive research based interviewing and completed a questionnaire evaluation of their training experience. This questionnaire was developed aiming to evaluate cognitive, skill-based and affective learning outcomes (Kraiger, Ford & Salas, 1993), providing construct-orientated evidence of validity. A peer evaluation of the application validity of the cognitive demands tables and training scenarios produced from the interviews was also completed in collaboration with experienced analysts. Additionally, data was checked with other engineering experts to establish how far they agreed with the cognition elicited and most importantly how far they concurred that this tacit information was not currently available to novices.

RESULTS

The engineers found the process of interviewing and being interviewed using the ACTA techniques initially challenging. The ability of both the interviewer as facilitator of cognitive knowledge elicitation, and the interviewee, to take time to reflect in a thoughtful, reflexive , meaningful and organised way were key to the success of the interviews. The participants found the training involved a great deal of focus which meant lots of thinking/rest breaks were required. As a result of this the authors and engineers developed a series of tips, shown in table 2 in order to maximise the task diagram and knowledge–elicitation phase of ACTA, recognising the importance of socio-cognitive competence/insight. This series of tips greatly assisted participants and added to the language and positive social context for knowledge transfer. The tasks covered by the managers/engineers varied according to their organizational role and included everything from plant trial management; complex decisions surrounded choice of experiments for fuel testing; running a new project; improving supply security; to preparing to meet a new customer. 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.

In addition to documenting task specific mental models, detailed perceptions of cues and strategies, an important feature which emerged to the surprise of the engineers was the importance of *hot/sensory based cognition*. For example several engineers described noticing peculiar smells in the mornings which resulted in adjusting the manufacturing process before the new petroleum additive was destroyed, making significant economic savings and avoiding potential hazards. The completed summary analysis/cognitive demands table were then used as a base for developing computer-based training which captured the lived expert realities of successful engineering tasks, clearly documenting mental models. The results of each ACTA were also subject to peer review which assisted knowledge transfer.

Feed-back from within the organisation has been positive with the practitioners wanting to utilise more CTA based training which provides such positive impact on organizational learning. The evaluation of the training suggested that the majority of participants felt that the ACTA techniques were *a very effective and efficient framework for helping articulate how experienced colleagues do specific tasks, provided structured learning and clear training outcomes*. One participant however, suggested that applying ACTA maybe particularly difficult in terms of *"drilling down to the right level of granularity of a task in order to access the most specific tacit knowledge".*

Table 2 Accessing Expertise in the Field: Top tips for getting rich data/ developing socio-cognitive competence/insight from ACTA

Redo and refine the task diagrams	Retrace your steps and redo the task diagrams as needed – you may need several drafts to get the detail level right
Listen actively throughout	ACTA works better if the interviewer listens actively: listen, summarise and then record the information (rather than writing notes throughout, as you are more likely to miss key information, particularly for the knowledge audit)
Stay focused and be clear about your roles	Reign in the temptation to share anecdotes, this can distract from the task, and remain clear about how interviews and who is interviewer (rather than inadvertently swopping during the process)
Bear with frustration	The process might entail some frustration about taking too long, or not getting the right level of detail– this is completely normal! If in doubt or getting too tired, leave the task for a while, and come back to it the next day
Ask what is difficult and ask about thinking	One of the key objectives for ACTA is to highlight what experts think, but might not have shared explicitly. So don't be shy to clarify, ask for more detail, or ask questions again in a different way. Your data should tap into thinking (so go beyond obvious outcomes)
Don't assume and choose your pairings wisely	You might think that things are obvious (as interviewer or interviewee) but chances are that they are not. It can work well to work in pairs or triads who don't usually work with each other, rather than pairing up with close colleagues. This will allow you to ask important questions which team members may not ask, assuming that the answers should be obvious (they usually are not!)
Remember that detail is good	As a rough rule of thumb, each component of your task diagram should be annotated with detail, and each aspect of the knowledge audit should fill about half a flip chart page
Be aware of when you stop recording information	If there is a time in the interview when you talk, but no information is recorded on the flip charts, then ask yourself 'why'. Are you not asking the right questions? Have you gone 'off track'?
Use the crib sheets	ACTA works best with structure, so don't be shy to use the crib sheets
Check your thinking	Do talk each other through your diagrams and knowledge audits again, for instance clarify anything which is not clear, and make sure the examples are specific, rather than general.

Limitations

Whilst ACTA and CTA techniques are established methods within the Human Factors, Psychology and Naturalistic Decision Making communities both with researchers and practitioners, few management researchers as yet, have adopted these techniques. Of the various perspectives which study judgment and decision making NDM has arguably made the greatest progress in industrial-organizational (I-O) psychology (Salas, Rosen and DiazGranados in press). Time intensive research activity is a 'nice to have' for many organisations and the management community may require these techniques to be adapted and modified further in order to translate to different domains of management practice. Evaluating the success of CTA based training requires a longitudinal approach which with this study we begin to offer. Continued research in this area also requires a shift in thinking and long term investment by more organisations in order to successfully manage knowledge learning transfer (Wang, 2010). In addition as the in-depth interview techniques are intensive and access System 2 thinking/cognition to reflect upon System 1 thought/cognition processes, careful interpretation, and mentoring is required. (Systems 1 thinking is characterized by fast, heuristic-based, emotional processing and is generally social and personal, and System 2 thinking is characterized by slower, controlled, analytical processing and is less social and less contextualised (Stanovich & West, 2000).

CONCLUSION

Tofel-Grehl and Feldon (2013) have noted the growing popularity of cognitive task analysis (CTA) in both research and practice and completed a meta-analysis of studies in order to examine the value of such training. They report that though their meta analysis is limited due to its small number of studies the effect of CTA instruction is large (Hedges's g=0.871). Also, whilst they note that effect sizes vary by CTA used and by training context our work to date concurs with their report and suggests that expert engineering information elicited with ACTA provides a strong basis for the highly effective training of novices. Whilst this work is on-going it aims to be original in its application as few studies document such applied inclusion of practitioners with the co-construction of knowledge. The study demonstrates the utility of: applying qualitative methods such as ACTA to the domain of petroleum management/engineering**;** understanding how engineering practitioners' can adopt and utilise ACTA techniques; developing & interpreting the co-construction of knowledge management within a macro-cognitive framework . The elicited scenarios will aim to assist novice engineering professionals: raise situation awareness in relation to specific tasks and clearly define cognitive complexity 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 (Donate & Canales, 2012) 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.

Our contribution to the development of CTA methods and knowledge management impact here strongly highlight the importance of recognising, managing and providing training which supports practitioners to develop their socio-cognitive competence and insight, alongside knowledge elicitation documentation and transformative knowledge management solutions. The complexities surrounding such knowledge transfer provide an interesting research agenda which utilises a range of theoretical and pragmatic contributions. Exploring the links theoretically between developing the reflexive System 2 thinking that the ACTA techniques require in order to reflect upon System 1 thinking also offer an exciting research agenda. We still have many more questions to answer however, concur with Hoffman et al (2014), and agree that (i) developing robust methods to accelerate expertise within organisations in order to assist knowledge acquisition and skills at a high level of proficiency in addition to (ii) facilitating the retention on knowledge and skill, will remain important to the future success of organisations training for resilience and adaptivity.

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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.

Chi, M.T.H., Glaser, R., & Farr, M.J. (eds.) 1988. The Nature of Expertise. Mahwah, NJ: Lawrence Erlbaum Associates.

Crandall, B., Klein, G., & Hoffman, R. H. (2006). *Working minds*. Cambridge: MIT Press.

Donate, M. J., & Canales, J. I. (2012). A new approach to the concept of knowledge strategy. *Journal of Knowledge Management, 16* (1), 22-44.

Ericsson., K.A. & Smith, J. (1991). *Towards a General Theory of Expertise: Prospects and Limits.* Cambridge, MA: MIT Press

Feltovich, P.J., Ford, K.M., and Hoffman, R.R. (eds.) (1997). *Expertise in Context.* Menlo Park MA: MIT Press

Gore, J. (2013). Transforming Knowledge: Capturing Engineers' Cognitive Expertise. *11th International Conference on Naturalistic Decision Making*, Marseille.

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.

Hoffman, R.R.,Ward, P., Feltovich, P.J., Dibello, L., Fiore, S., & Andrews, D.H. (2014). *Accelerated expertise*. New York: Psychology Press, Taylor & Francis.

Kahneman, D., & Klein, G.A. (2009). Conditions for intuitive expertise: a failure to disagree. *American Psychologist.* 64(6). 515-526.

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.

Koehler, D.J. and Harvey, N. (2004). Expertise in judgement and decision making : a case for training intuitive decision skills in *Blackwell Handbooks of Experimental Psychology : Blackwell Handbook of Judgement and Decision Making.* London, Blackwell.

Kraiger,K., Ford.J.K. & Salas, E. (1993). Application of cognitive, skill-based, and affective theories of learning outcomes to new methods of training evaluation. *Journal of Applied Psychology* Vol 78. No2, 311-228.

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*.

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 , 353-36

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.

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.

Roth, E., Ohara, J., Bisantz, A., Hoffman, R., Kelin, G., Militello, L., Pfautz, J.D. (2014). How to recognise a "good" CTA ? Proceedings of the Human Facors and Ergonomics Scoiety 58th Annual Meeting: 320-324.

Salas, E., Rosen, M.A. & DiazGranados, D. (2015 in press.) Naturalistic decision making in indviduals and teams. In S.W.J. Kozlowski (Ed). *Oxford Handbook of Industrial and Organizational Psychology*. New York: Oxford Univeristy Press.

Stanovich, K. E., & West, R.F. (2000). Individual differences in reasoning: Implications for the rationality debate. *Behavioral & Brain Sciences, 23*(645-665).

Tofel-Grehl, C., & Feldon, D.F. (2013). Cognitive task analysis-based training: A meta analysis of studies. *Journal of Cognitive Engineering and Decision Making 7 : 293-304*

Wack, P. 1985. Scenarios: Unchartered waters ahead. *Harvard Business Review.* Sept-Oct

Wang, S. & Noe, R. A. 2010. Knowledge sharing: A review and directions for future research, *Human Resource Management Review, 20*, 115-131.

Wilkinson A. & Kupers, R. 2013. Living in the futures: how scenario planning changed corporate strategy. *Harvard Business Review*. May.