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Eliciting Expert Knowledge to Inform Training Design

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ABSTRACT

Purpose: To determine the elicitation methodologies best placed to uncover and capture the expert operator's reflective cognitive judgements in complex and dynamic military operating environments (e.g., explosive ordinance disposal) in order to develop the specification for a reflective eXplainable Artificial Intelligence (XAI) agent to support the training of domain novices.

Approach: A bounded literature review of the latest developments in expert knowledge elicitation was undertaken to determine the 'art-of-the-possible' in respects to uncovering an expert's cognitive judgements in complex and dynamic environments. Candidate methodologies were systematically and critically reviewed in order to identify the most promising methodologies for uncovering expert situational awareness and metacognitive evaluations in pursuit of actionable threat mitigation strategies in high-risk contexts. Research outputs are synthesized into an interview protocol for eliciting and understanding the in-situ actions and decisions of experts in high-risk, complex operating environments.

Practical implications: Trainees entering high-risk operating environments can benefit from exposure to expert reflective strategies whilst learning the trade. Typical operator training focusses on technical aspects of threat mitigation but often overlooks reflective self-evaluation. The present study represents an initial step towards determining the feasibility of designing a reflective XAI agent to augment the performance of trainees entering high-risk operations. Outputs of the expert knowledge elicitation protocol documented here shall be used to refine a theoretical framework of expert operator judgement, in order to determine decision support strategies of benefit to domain novices.

CCS CONCEPTS

• Psychology • Decision analysis • Decision support systems

KEYWORDS

Expert knowledge elicitation, literature review, decision support, explainable artificial intelligence

1 Introduction

The future operating environment for UK military personnel is envisioned to be volatile, uncertain, complex and ambiguous (VUCA, e.g., [1]). Military personnel are facing situations where they are required to operate in contested environments against hidden adversaries whilst pursuing multiple and sometimes conflicting goals (e.g., delivering humanitarian aid whilst deterring terrorist activity). To prepare for operations in VUCA environments there is increasing demand for developing human cognitive capability at the individual level, in order to support activity conducive to increased situational understanding at the tactical level [2]. The present paper outlines initial research into a feasibility study developing XAI reflective agents in order to augment operator training in the explosive ordinance disposal domain. XAI agents work in a transparent, explainable and understandable manner, which underpins the trustworthiness of its decisions. The development of XAI

based decision-support systems within such contexts requires careful analysis of expert operator activity to infer the key cognitive strategies that aid in successful threat assessment. The first step towards developing an XAI agent was to generate a methodological protocol for expert knowledge elicitation (KE) concentrating on pattern recognition, sensemaking and self-evaluation.

2 Methodology Review

A systematic literature review was conducted to determine the methodologies best suited to elicit the decision making expertise. Care was taken to ensure consideration of source selection and evaluation criteria were in line with guidance on review rigor and replicability [3, 4]. The review process informed the design of the KE protocol described later on. A phased approach was taken as detailed in Figure 1.

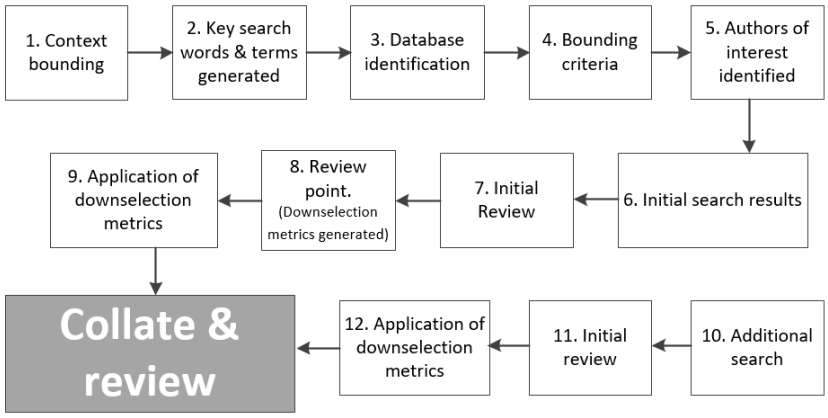

Figure 1: The systematic literature review process

Firstly, key terms were defined. Complexity was interpreted to mean any environment where there was a VUCA element. Expert decision-making was interpreted as encompassing both the conscious and subconscious expertise brought to bear in forming a decision in a complex environment. The following key words were generated by one researcher and reviewed/approved by the rest of the research team:

a. KE technique [AND repertory grid / cognitive interview / threat assessment / threat monitoring / risk interview / risk assessment / threat-strategy interview / critical incidents / risk monitoring / vulnerability / knowledge acquisition techniques / laddering / scaffolding];
b. Expert cognitive walkthrough;
c. Naturalistic decision-making [OR complex decision-making / recognition-primed decision-making / meta-recognition decision-making / recognition / intuition];
d. Additional keyword criteria, reflecting expert discrimination [discrimination / distinction / categorization] were added to the project at a later date (Figure 1, Step 10).

For the purposes of simplicity, and to avoid undue replication and redundancy in search outputs, one academic database, Science Direct, was searched as a pilot literature search indicated that the majority of papers of interest were available through this peer-reviewed database. As a further line of enquiry regarding methodological review, a number of key authors were noted. Both theoretical, review and empirical papers were sought so long as they met the following criteria:

- A review / theoretical / empirical paper concerned with the elicitation of expert knowledge;
- Published between 2013-2018. Initial scoping of the literature indicated that this date range returned an appropriate amount of results including a previous relevant review article [5].

Bounding criteria. Further exclusion criteria were discussed as the literature review unfolded. Key terms for potential literature source exclusion included: industrial applications / computer software / systems engineering contexts; empirical papers involving patient or child samples; the use of big-data and/or Bayesian methodology; and technological applications (e.g., interface design, serious games).

Initial literature searches were performed by one researcher after which a review point was utilized to discuss outputs and also determine and define the downselection criteria going forward (see Table 1.).

Due to the practical difficulties in conducting research in VUCA domains, coupled with a requirement to focus on the most promising methodologies, it was agreed that downselection would focus on those publications where the averaging of two independent raters outputted a methodology score of relevant or extremely relevant (4+), and a context rating score that was at least 'somewhat appropriate' (3+). Of the 2489 returned results, 47 were identified for inclusion following the initial abstract-based literature review. Full-text versions of the selected 47 articles were retrieved, and subsequently 20 articles were judged as relevant for collation and full inspection via the re-application of the agreed downselection metrics.

Table 1. Downselection criteria

Rating Score	Methodology	Context
1	Not relevant	Not appropriate
2	Barely relevant	Barely appropriate
3	Somewhat relevant	Somewhat appropriate
4	Relevant	Appropriate
5	Extremely relevant	Extremely appropriate

3 Review Outputs

3.1 Classification of elicitation methods

Expert knowledge can be elicited by means of various direct or indirect methods [6], as indicated in Figure 2 below. Direct methods involve documentation analysis, observations, interviews, verbal and non-verbal process tracing methods [7], while indirect methods involve conceptual methods, such as repertory grids or card sorting. From the studies reviewed in the present paper, some opted for using a single KE method, while others combined multiple methods. These basic distinctions were used as the basis for the classification of articles in the review.

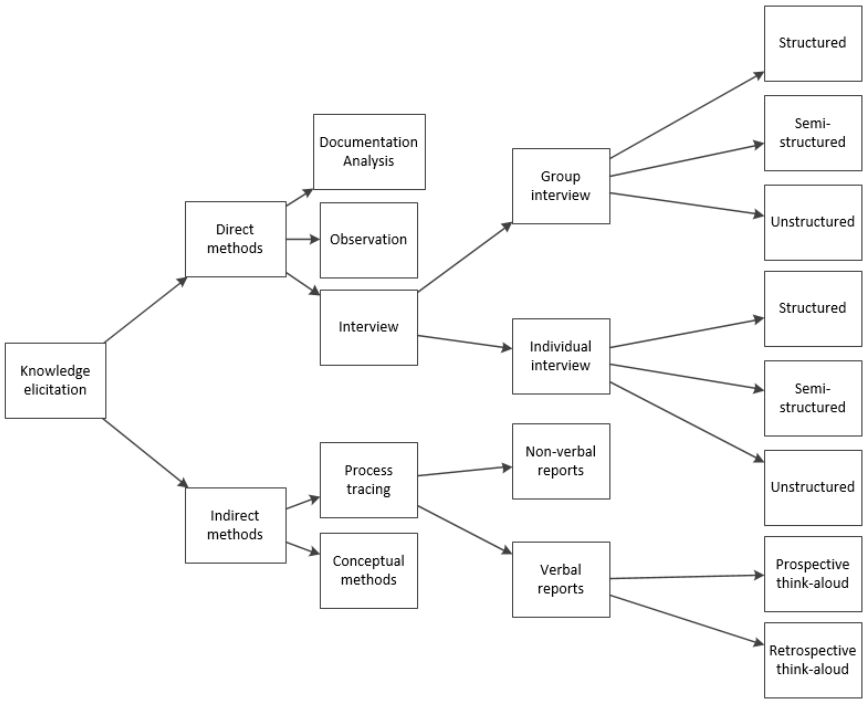

Figure 2: Basic categories of elicitation methods [6, 7]

3.2 Findings

The summary of the KE methodologies outputted are summarized in Table 2. Upon reviewing the KE studies from 2013-2018 in the field of complex, dynamic decision-making, it is apparent that there is no gold-standard methodology being used for expert KE. The present review applied a limited time frame (5 years) but nevertheless returned a rich and varied number of KE methods.

Table 2: Summary of the review findings

Category		Elicitation Method	N	References
A. Single-method Approach				
Direct methods	Documentation analysis	Accident reports Mandatory incident reports Literature on expert judgements	1	[8] Mazaheri et al. (2016)
	Interviews	Individual structured or semi-structured interviews:		
		Critical decision method (CDM)	4	[9] Plant & Stanton (2013) [10] Plant & Stanton (2015) [11] Plant & Stanton (2017)
		CDM & Schema world action research method		[12] Plant & Stanton (2016)
		Threat strategy interview	1	[13] Durso et al. (2015)
		Critical incident interview	1	[14] Schubert et al. (2013)
		Fuzzy cognitive mapping	1	[15] Jetter & Kok (2014)
		Questionnaires	2	[16] Huang & Smidts (2017) [17] Edlmann et al. (2016)
	Process tracing	Collegial verbalisation method	1	[18] Axelsson & Jansson (2018)
Indirect methods	Conceptual techniques	Repertory grid and laddering	2	[19] Dey & Lee (2017) [20] Burr & King (2017)
B. Multi-method Approach				
Direct methods	Observation & interviews	Observation & individual interviews & group interviews & questionnaires & document analysis	2	[21] Fogli & Guida (2013)
		Semi-structured individual interview & questionnaire		[22] McNeese et al. (2017)
	Observation, interviews, process tracing	Observation, simulation & structured individual interview	1	[23] Naweed (2014)
Direct & indirect methods	Documentation analysis, observation, interviews, & conceptual techniques	Documentation analysis & observations of real-life scenarios & conceptual interviews & questionnaires	1	[24] Malakis & Kontogiannis (2013)
C. Methodological Comparisons				
Direct methods	Observation & interviews	Observations, Unstructured interviews, Semi-structured interviews based on partial scenario descriptions, Semi-structured interviews based on complete scenario descriptions, Semi-structured interviews based on full process descriptions	1	[25] Christov et al. (2017)
Direct methods	Interviews	Logical rule-based system Fuzzy rule-based system	1	[5] Bimba et al. (2016)
Direct methods	Interviews	Structured interview, Product pattern, Brainstorming, Concepts mapping	1	[26] Vásquez-Bravo et al. (2014)

Each elicitation method has inherent strengths and limitations (although these are not always overtly discussed in the published articles). No single KE method can capture all of the critical process steps and therefore a combination of different methods is advised [24]. What is more important is to

articulate the justification for using a specific combination of elicitation techniques, the strength and weaknesses of the overall elicitation methodology, and to explain how the information elicited through the various methods can be combined in a way that strengthens the elicited knowledge base. For this reason it is important to understand the nature of knowledge elicited through the various methods and to explain the purpose and use of each method within the overall methodological protocol. While studies using a combination of methods may have been aware of these considerations, they did not explicitly discuss these aspects of the KE methodology in the publications. Detail is missing as to the theoretical background of the elicitation methods, how their underlying theoretical framework requires the combination of methods, or the pragmatic aspects of combining KE methods. Therefore, it is concluded that the design of a novel multi-method elicitation methodology with explicit guidelines and justifications should be of benefit to examining expert decision-making in complex domains.

3.3 Implications of the findings

There is a need to develop a novel elicitation methodology that can capture expertise in complex, high-risk domains. Stanton [27] argues that the combinations of existing methods can be the source of new methodology development. Combining KE methods that complement each other by focusing on different aspects of expert knowledge may be most suitable when developing a thorough elicitation protocol to uncover expert domain-specific strategies. It is equally important to articulate the reasons for the combination of certain methods by taking into account their theoretical underpinning and what they aim to achieve. A methodology that combines documentation analysis, semi-structured interviews, process tracing, and conceptual methods, using a combination of retrospective and concurrent, direct and indirect elicitation techniques, whilst exhaustive, would also be the most comprehensive and able to mitigate against the inherent limitations of individual methods. It is also important for the methodology to combine elicitation methods in an integrative approach where the methods not merely follow each other independently, but where they build upon and extend each other's findings.

4 Recommended protocol specifications

The KE methodology presently recommended for the purposes of eliciting expert strategies from operators in complex environments consists of four stages, encompassing a range of KE methods (see Figure 3):

Stage 1: Domain specific documentation analysis - The aim of the documentation analysis is twofold: 1) to familiarize the researchers with the standard operating procedures, the documented guidelines, and the permitted actions in the domain of interest; and, 2) to develop a domain-specific model of key decisions and recognized actions within that domain. This framework will need to include the important action/decision points, and the relevant enabling conditions and operating prerequisites. Once drafted, the framework must be contextualized, critiqued, refined and validated via consultation with key subject matter experts. Outputs of this stage will include a list of requisite cognitive and metacognitive variables that underpin expert strategizing and form the basis for targeted XAI simulation and training.

Stage 2: Theoretical review - With a view to contextualizing the list of requisite cognitive and metacognitive variables outputted from Stage 1, a theoretical review of the cognitive science literature should be undertaken to contextualize and reinforce the scientific literature basis for the model. It will provide further details and enrichment for the model via determining how existing theory might be exploited in order to determine what connections might exist between the cognitive and metacognitive model elements.

Stage 3: Retrospective expert elicitation direct and indirect methods - Stage 3 of the elicitation process has two phases. Phase 1 entails a repertory grid-based expert personal construct elicitation [20, 28]. The aim of this technique is to elicit expert constructs, formed through years of experience and reliant on skilled pattern recognition, domain knowledge and intuition. During repertory grid, the participant

shall be asked to compare and contrast various incidents (both routine and non-routine) where they have had responsibility for constructing a threat assessment and executing a threat mitigation strategy. The list of elicited constructs shall then be mapped to the requisite variables outputted at Stage 1 (documentation analysis), with an additional 'Else/other' open category to pick up on anything not covered in the pre-defined variables. This cross-validation opportunity will provide further scrutiny of the model.

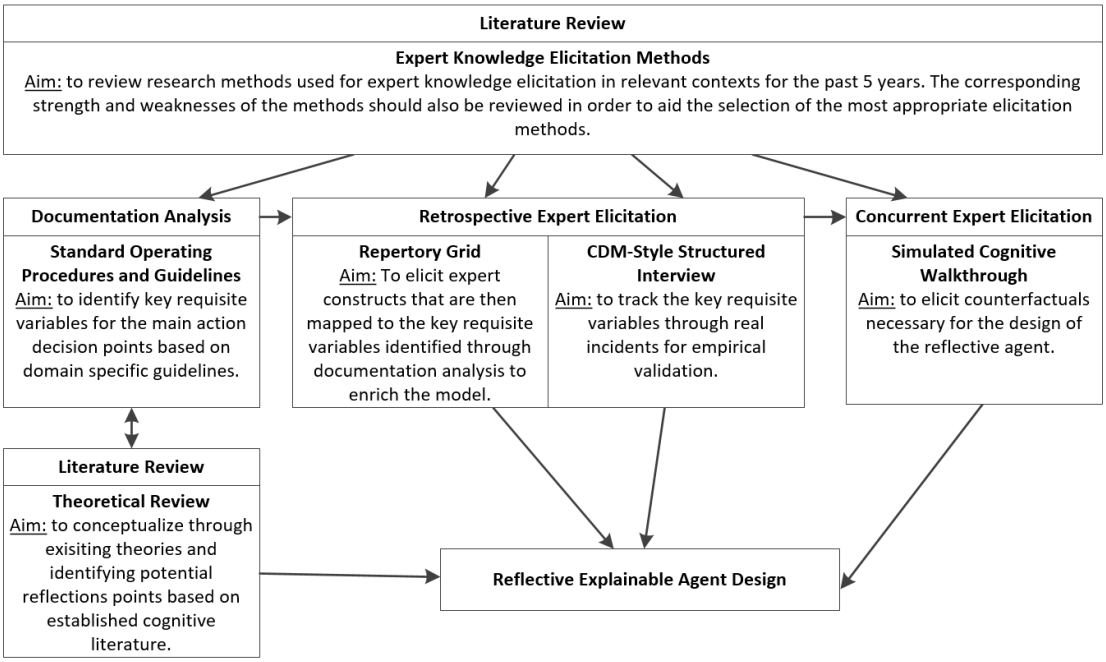

Figure 3: Recommended protocol specifications

Phase 2 of the retrospective elicitation involves a CDM-style semi-structured interview with the aim of scrutinizing the key requisite variables of the model through real incidents. In this stage the participants are asked to recall a challenging incident they have been involved in, followed by timeline construction, general incident probes, and then in-depth, decision-by-decision analysis. In an extension to the CDM methodology, prompts will be developed in order to allow the application and tracking of the cognitive and metacognitive requisites as applicable throughout the incident timeline. Further prompting will allow for exploration of requisite triggers and consequences.

Stage 4: Concurrent expert elicitation interviews through simulated scenario walk-throughs
The final stage of the elicitation involves concurrent think-aloud procedures with simulated scenarios. The aim here is to further validate the model through reflection-in-action and elicit counterfactuals, or 'what-ifs'. These will provide various links and rules between the constructs, requisite variables and cognitive courses of actions that will be vital for the design of the AI agent.

5 Future research

This systematic expert KE methodological review has been undertaken with a view to the design and generation of a protocol for eliciting and capturing expert task-based cognitive and metacognitive strategies in dynamic VUCA contexts. Initial research has focused on reviewing the KE methods available, identifying those of utility to present purposes, and developing a staged protocol for uncovering the nature and contexts in which experts call upon decision-making requisites to inform their threat assessment and self-evaluate task progress. An emphasis has been placed on the requirement to map elicitation methods to natural expert information processing and involving subject matter experts in scrutinizing the developed protocols. A road map has been generated to determine how best to draw together various research threads and KE methodologies in order to identify expert

cognitive strategizing and challenging task scenarios that can be used to inform specifications and requirements of a reflective XAI agent. The ultimate goal of the XAI agent shall be to facilitate domain-specific decision-making by prompting reflective strategies amongst domain novices to augment training.

In the first instance, the protocol will be tested through application to explosive ordinance disposal in the military domain. This shall entail review of operating procedures as well as the elicitation and exploration of the expert cognitive strategizing and reflective rationalizations aligned to challenging explosive ordinance disposal incidents. Outputs shall be used to create a simulated training scenario with an embedded XAI agent to augment the reflective capability of trainees. Further high-risk VUCA military environments, involving dynamic changes in threat identification and/or risk mitigation are likely to benefit from the application of the protocol developed presently. Outside of the military domain, candidate VUCA domains that may benefit from the protocol developed include emergency responding (e.g., firefighting, public disorder). Further VUCA domains, without risk to life but still requiring complex risk mitigation, might include the detection of intrusion in computerized networks (e.g., fraud or cyber attack detection). Should XAI agents be required in these domains, those involved might benefit from the present methodological synthesis.

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*Note: *indicates a publication included in the systematic review of knowledge elicitation methods*

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