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Concept Development for Future Domains: A New Method of Knowledge Elicitation

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During the development of operational concepts for the Future Combat System of Systems' Unit of Employment and Unit of Action it became clear that the Army needed a more effective and efficient method for envisioning the future. A review of existing knowledge elicitation techniques indicated that current methods are not easily applied to the development of future concepts. They do not adequately address the cognitive impact new concepts and technology have on Soldiers. In addition, existing methods do not thoroughly examine the potential unforeseen impacts the introduction of the new technology will have. The inherent difficulty in envisioning new concepts requires a more systematic approach to elicit knowledge from domain experts. This report reviews existing methods and describes a new method of knowledge elicitation to more effectively support the development of future concepts, evaluate the impact of new technology, and solve difficult problems where information and expertise is dispersed among many individuals.

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FOREWORD

As new technologies, concepts, and doctrine are introduced into the Army's operational systems there is a corresponding change to the cognitive processes and procedures used to effectively adapt to the "new way of accomplishing a task." A serious challenge to the U.S. Army transformation effort is the ability to develop realistic concepts, systems, and technologies for the future. Effective, systematic techniques of concept development and knowledge exploration for envisioning future systems and operations are currently not available.

Understanding the dynamic interactions between people, technology, and tasks; realistically being able to predict new technologies and their impact on cognitive processes; and predicting and anticipating potential challenges and unintended side effects will be key enablers for the transformation process. All too frequently new technologies are introduced without even a basic understanding of these relationships and the resulting systems are too burdensome to the Soldier or far too cognitively demanding to use during the stress of battle. This report reflects ongoing work by the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) as part of its Science and Technology Objective: IV.SP.2002.02, Methods and Measures of Commander-Centric Training to develop new methods to enhance the U.S. Army's ability to produce new concepts and training needed to support the transformation effort. The techniques outlined in this report are being applied to ongoing research efforts.

The findings of this research have been briefed to representatives of the Unit of Action Maneuver Battle Lab (UAMBL), to Fort Knox officers who serve as Future Force Unit of Action Command and Staff in UAMBL exercises, to the Unit of Action Experimental Element, and to members of the Lead Systems Integrator Training Integrated Project Team.

MICHELLE SAMS
Technical Director

CONCEPT DEVELOPMENT FOR FUTURE DOMAINS: A NEW METHOD OF KNOWLEDGE ELICITATION

EXECUTIVE SUMMARY

Research Requirement:

The U.S. Army is in the process of transforming to a Future Force with increased reliance on technology. The transformation requires the development of new concepts, processes, procedures, doctrine, knowledge, and ideas. During the development of operational concepts for the (FCS) Unit of Employment and Unit of Action it became clear that the Army needed a more effective and efficient method for envisioning the future. Traditional methods of concept development and knowledge exploration are limited in their ability to generate realistic and reliable concepts about the future. While an impressive list of candidate technologies and concepts can be conceived, the Army cannot afford to become too optimistic about their influence without having a method to appropriately evaluate their impact. There is a tremendous need for a powerful, yet flexible, approach to concept development and knowledge exploration that can cope with the unique difficulties of envisioning and studying future concepts.

Procedure:

U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) examined methods to generate, refine, test, and validate new concepts related to doctrine, tactics, techniques, procedures, and technology integration. The present report reviews existing methods of concept development and knowledge exploration and analyzes the appropriateness of those methods for envisioning future concepts. A new method of concept development and knowledge elicitation that allows for the systematic investigation of future concepts is proposed.

Findings:

The current research concluded that existing methods of concept development and knowledge elicitation are not appropriate and are not effective for examining future issues. The inherent difficulty in envisioning new concepts is explored and existing methods are described. A new method, incorporating components of existing methods, was developed to provide a potentially powerful approach to systematically investigate future concepts. Information on implementing the method and understanding the impact of future concepts and technology is provided.

Utilization and Dissemination of Findings:

The findings of the research can benefit personnel in the U.S. Army Training and Doctrine Command, the Unit of Action Maneuver Battle Laboratory, and other agencies involved in concept development, the development of new doctrine, and the elicitation of

realistic ideas for the Future Force. Further, the outcomes of the research have been applied to the development of new training methods for the U.S. Army and the U.S. Army National Guard.

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Introduction

The U.S. Army is currently in the process of transforming into a strategically responsive force capable of rapid deployment and effective operations in all types of military missions. Under the transformation effort, the Army is changing the way it equips, organizes, deploys, and trains. The cornerstone of the transformation is the Future Force and the (FCS). The FCS is envisioned to be a distributed, network-centric, multi-mission combat system that will utilize advanced, state-of-the-art technologies. To support the transformation effort the Army is developing a family of 18 networked war-fighting systems which are more lethal, survivable, deployable and sustainable than the existing arsenal of Army systems. The FCS is envisioned to be equipped with a combination of manned, robotic, and mixed (man and robotic) human-in-the-loop equipment.

It is predicted that the network of systems will allow unprecedented information transfer. The extensive amount of information will attempt to compensate for the loss of armor afforded by current systems and is assumed to allow for superiority and synchronized operations to see, engage, and destroy the enemy before the enemy detects the Future Force. It is predicted that the network centric approach will allow for an improved integration of communication across and within echelons. Further, the FCS, and its accompanying Future Force, is envisioned to operate as part of a combined, joint, interagency, and multinational team. The key enablers of this vision for information superiority are the rapid technological advances and the integration of information across the military. One of the most challenging problems facing the Army is to determine how to integrate and capitalize on future capabilities without having a clear understanding of what those capabilities are or how they should be implemented.

The standard belief that the introduction of new technology is a simple process that will result in improved organizational performance is an oversimplification fallacy (Feltovich, Spiro, & Coulson, 1997; Woods & Dekker, 2000). With regard to technological advancement in the U.S. Army, Wass de Czege and Biever (1998) highlight this point suggesting that "combat power is not simply the sum of machine performance; it requires individual and organizational competence and synergy" (p. 19). Thus, a change in technology produces a corresponding change in the operational and cognitive systems – resulting in the transformation of existing roles, processes, and procedures and the development of new ones.

Any assertion concerning the impact of future technologies represents a hypothesis regarding the relationship and dynamics of the new technology to people and existing systems (Woods, 2002; Woods 1998). The hypotheses, once observed and evaluated, often prove to be incorrect once the second order effects of the system are realized (Sarter, Woods, & Billings, 1997). Thus, as Woods (2002) suggested, "envisioning the future of operations, given the dynamic and adaptive nature of the process, is quite fragile" (p. 2).

Even if the new technology is successfully integrated, the technology, in and of itself, does not allow for improved performance. In fact, the insertion of new technology may increase cognitive demands (Howell & Cooke, 1989). The technology must be coupled with corresponding changes to all facets of the system. The point was made vividly clear by Cordesman and Wagner (1996) in their review of the Gulf War. The authors stated,

> Much of the equipment deployed in U.S., other Western, and Saudi forces was designed to ease the burden on the operator, reduce fatigue, and simplify the task involved in combat. Instead, these advances were used to demand more from the operator.
>
> Almost without exception, technology did not meet the goal of unencumbering the military personnel operating the equipment, due to the burden placed on them by combat. As a result, weapons and support systems often required exceptional human expertise, commitment, and endurance. The Gulf War shows that there is a natural synergy between tactics, technology, and human factors and effective military leaders will exploit every new advance to the limit. As a result, virtually every advance in ergonomics was exploited to ask military personnel to do more, do it faster, and do it in more complex ways.
>
> This stress occurred whether the issue was flying and sustaining higher sortie rates, conducting faster armored maneuvers over longer periods of time, targeting and firing at longer ranges, or increasing the speed of logistic support. Wars may occur in which one side is so superior that it can rely on tactics and technology without a matching improvement in manpower, and without stressing human factors to their limit. Such wars, however, are unlikely to involve significant levels of conflict, and the idea that technology can reduce the stress of combat or the need for manpower quality and readiness is almost certain to be a myth. While there is no way to prove such a conclusion, one very real lesson of the Gulf War is that new tactics and technology simply result in altering the pattern of human stress to achieve a new intensity and tempo of combat. (p. 25)

The future of U.S. Army dominance will not continue to be as dependent on the Department of Defense (DoD) designing, building, and protecting unique technologies. Instead, dominance will be maintained by designing, implementing and protecting the world's best technology integration process (Carter & White, 2000). This is a different way of doing business. It is predicated on the notion that the U.S. will be the fastest integrator of new technologies – into the hardware, into the software, into our doctrinal and organizational systems, and into our training and leader development process. A key to success is a solid Army process for concept development – a means to generate, elaborate, refine, describe, test, and validate new Future Force concepts relating to doctrine, tactics, techniques, procedures, unit and team organization, job allocation, training, leader development, and other aspects of technology integration.

How do we best use the total Army team – warfighter, scientist, theorist, analyst, and engineer – in the development process of future concepts? There is a critical need to create the methods needed to systematically extract critical information (knowledge elicitation) about the future issues in order to more effectively and efficiently manage the concept development (knowledge creation) and integration process. This report addresses that need by reviewing existing methods and documents a new, systematic method of knowledge elicitation to address the Army's need for a formalized process for concept development.

Importance of Knowledge Elicitation

Expert knowledge involves the reasoning, judgment, and performance of individuals who are unusually accurate, skillful, and reliable in their domain. The knowledge is mostly heuristic, based on experience, and inaccessible through standard observational methods. Knowledge elicitation describes a process in which a researcher or analyst captures knowledge, procedures, and strategies through systematic interaction with domain experts for the purposes of building expert models and developing expert reasoning strategies. The focus on expert knowledge has three functions: (a) to improve and support human performance in decision making tasks; (b) to design instruction to efficiently and efficiently train individuals; and (c) to automate task functions that consist of human logic processes.

Traditional methods of knowledge elicitation often rely on direct observation of expert behaviors. The outcomes of these elicitation efforts can be decomposed to describe knowledge that is linked to observable behaviors within a specific domain and context. In addition, other methods have been developed to capture internal cognitive processes that are not readily accessible by observing behavior. While much research has been conducted on concept development and knowledge elicitation, the acquisition of expert knowledge still remains one of the most time-consuming, tedious, and essential tasks in designing systems (Chervinskaya & Wasserman, 2000).

Concept development for the Army Future Force involves future systems and developing technological capabilities. It is concerned with future operational capabilities, training, and doctrine; it addresses how those systems should be developed and how they will be employed. When the goal of knowledge elicitation is future concept development, experts are required to generate best-guess estimates based on an anticipated set of new capabilities. In other words, while the participants in the knowledge elicitation exercise may be experts in their current domain, they will be asked to theorize and reason on how things might be different under various projected future conditions. How does knowledge generalize to future systems where detailed specifications of developing technology are not yet known? How does expertise in a current domain inform the development of concepts for future products and practices?

Current Army Methods for Concept Development and Knowledge Elicitation

Generally, the Army has used two methods to elicit new knowledge and ideas from experts. The first is to have a strong theorist or analyst develop and present new concepts, i.e., an Army thinker thinks and then writes. A good example of this is *Conceptual Foundations of a Transformed U.S. Army* by Wass de Czege and Sinnreich, (2002). While strong creative thinkers are clearly a vital part of the effort, some drawbacks are evident in the 'just let thinkers think' method of concept development. The results are often very general, have not benefited from concrete attempts to implement the ideas, have not uncovered difficulties through instantiation, can be hard to communicate, and do not easily avail a team of specialized contributors working jointly. Several efforts less successful than the above-cited example could be mentioned with regard to Future Force concepts, producing documents that are poorly thought out, too general, impractical, unrealistic, fragmented, disjointed and contradictory ‘cut-and-paste’ efforts.

A second Army method is to stand up a replica of the new system and conduct a unit exercise in simulation, such as a focused Combat Training Center (CTC) rotation or Advanced Warfighter Experiment (AWE). Such full-scale events can be effective demonstrations of moderate-to well-developed concepts but have drawbacks, especially in the earlier stages of concept formation. They are expensive and require great effort and coordination to conduct, do not allow flexible manipulation of variables, present great measurement difficulties, and lack the repetition necessary to reach well-founded conclusions. Further, the complexity of conducting the event tends to overwhelm the experimental intent.

A limitation of both approaches is that they often do not account for the realization that the new concept, technology, or process will likely transform what it means to be an expert in the field. As Woods and Dekker (2000) suggest, “introducing new technology is not manipulating a single variable, but a change that reverberates throughout a system transforming judgments, roles, relationships, and weightings on different goals” (p. 5). There is a need to investigate intermediate concept development and exploration methods to augment the two extremes described above, methods that provide structured activities to measure, assess, and guide the concept development process yet are flexible enough to respond rapidly to a wide range of conceptual constructions.

Systematic Methods of Analysis

Systematic methods for knowledge acquisition and concept development are available. These methods have been developed based on cognitive and applied behavioral science principles and provide structured processes by which critical information about task knowledge and performance can be identified.

Methods of Task Analysis

Task analyses are systematic approaches to understanding, describing, and defining a job in terms of the physical and cognitive processes needed to successfully perform particular tasks. That is, task analytic methods help to identify the knowledge, skills, abilities, and other characteristics required to perform a job. They address the frequency, difficulty, criticality, conditions, performance standards, and importance of specific tasks. This report makes a distinction between traditional behavioral approaches to task analysis and cognitive task analysis.

Traditional task analysis focuses on the way a task is performed – the task is directly observable with a clear beginning and ending point (Department of Defense, 2001). Several methods have been used to gather information in traditional task analytic investigations. The most frequently used method to capture task information is through the use of individual and/or group interviews with subject-matter experts. Task analysis information is also collected using questionnaires and direct observation of incumbent subject-matter experts.

McCormick, Jeanneret, and Mecham (1972) make a distinction between job- and worker-oriented methods stating, “The job-oriented concept typically would be reflected by the use of specific task statements . . . the worker-oriented concepts typically would be reflected by the use of descriptions of reasonably definitive human behaviors” (p. 348).

Job-oriented task analysis focuses on what the task involves regarding the activities, tools, products, and outcomes of the task. Job-oriented task analysis is a systematic process for breaking tasks down into discrete step-by-step segments. Typically, this is accomplished by interviewing experts and by observing as the tasks are completed. The outcome of a job-oriented task analysis is a list of tasks and subtasks such as can be found in an Army Training and Evaluation Program (ARTEP). For example, the task Control Tactical Operations is subdivided into eight subtasks: Manage CS/CSS Force Positioning, Manage Use and Assignment of Terrain, Maintain Synchronization, Control Tactical Airspace, Plan Actions, Sequels, and Branches, Make Adjustments to Resources, Concept of Operations, or Mission, and Coordinate Actions to Produce Maximum Effective Application of Military Power (ARTEP 3-91, Draft). Techniques classified as job-oriented task analysis methods include the Functional Job Analysis (Fine & Wiley, 1971), Comprehensive Occupational Data Analysis Program (Christal & Weissmuller, 1976), and the Task Inventory Analysis.

Worker-oriented task analysis focuses on requisite characteristics of a subject-matter expert or job incumbent expressed in terms of knowledge, skills, abilities, and other characteristics. Worker-oriented task analysis techniques are typically used to identify the activities required to complete a task and does not specifically identify what the individual actually does (Burnett & McCracken 1982). Techniques classified as worker-oriented task analysis methods include the Position Analysis Questionnaire (McCormick, Jeanneret, & Mecham, 1972), Critical Incident Techniques, Occupational Analysis Inventory (Cunningham, Boese, Neeb, & Pass, 1983), Common-Metric System (Harvey, 1993), and the Job Element Method (Primoff & Eyde, 1988). Figure 1 provides a more comprehensive list of task analytic methods. Please see Kirwan & Ainsworth (1992) and Jonassen, Hannum, & Tessmer (1989) for a more extensive review of methods.

Job- and worker-oriented methods are very effective in specifying job requirements, characteristics, and system functions for observable jobs or sets of task. They are not, however, effective or efficient in systematically developing an understanding of cognitive processes or knowledge requirements. For example, the tasks and subtasks listed above from Army ARTEP 3-91 do not indicate anything about the mental processes experts go through to perform the task well. As Gott (1998) stated, “Complex job environments require deeper cognitive analyses that can ferret out the conceptions and reasoning processes that lurk behind observable behaviors” (p. 11). Cognitive task analysis provides a systematic process for identifying the cognitive elements and activities needed for task performance and is useful when there are few readily observable behaviors. The focus is on knowledge and cognitive processes as opposed to a breakdown of procedural steps.

Ability Requirements Scales Activity Sampling Behavioral Task Analysis Checklist Common Metric Questionnaire Common-Metric Systems Critical Incident Technique Decision-Action Diagramming Decomposition Method Fleishman Job Analysis Survey Focus Groups Functional Analysis System Technique Functional Job Analysis Scales Goal Composition Groupware Task Analysis Heuristic Task Analysis Process Integrated Performance Modeling Environment Interface Survey Interviews Job Components Inventory Job Element Inventory Job Elements Method Link Analysis Multipurpose Occupational Systems Analysis Inventory-Closed Ended	Nominal Group Technique Observation Occupational Analysis Inventory Operational Sequence Diagrams Operator Function Model Petri-nets Position Analysis Questionnaire Procedural Task Analysis Questionnaires Scenario-Based Analysis Sequential Task Analysis Signal Flow Analysis Table Top Analysis Task Decomposition Techniques Task Inventory/Comprehensive Occupational Data Analysis Programs Threshold Traits Analysis (TTA) Timeline Analysis Trigger Analysis Verbal Protocols Walk-Through Analysis Work Profiling System (WPS) Workload Analysis

Figure 1. Listing of Task Analysis Methods.

There are many methods of cognitive task analysis, each with unique elements designed for various settings and objectives. All the methods typically involve three phases: a description of the task environment, identification of related tasks and processes, and the elicitation of knowledge (DuBois, Shalin, Levi, & Borman, 1995). One example is called the critical decision method. In this method a facilitator asks experts to recall a salient incident or cases. In most situations, the case identified represent non-routine incidents where expert performance can be highlighted. The incidents become the focus of semi-structured interviews where cognitive probes are used to understand the experts' situation assessment and decision making processes. Appendix A provides a brief description of some major cognitive task analysis techniques. Appendix A is not intended to be an exhaustive presentation of such methods. Rather, the examples were chosen to represent the variety of methods currently employed. Figure 2 provides a more complete list of methods and techniques. Please see Schraagen, Chipman, & Shalin (2000) for an extensive review of cognitive task analysis methods.

Applied Cognitive Task Analysis	Magnitude Estimation
Active Participation	Minimal Scenario Technique
Activity Sampling	Multidimensional Scaling
Behavioral Descriptions	Object Oriented Modeling
Card Sorting	Observation
Cloze Technique	On-Site Observation
Cluster Analysis	P Sort
Cognitive Structure Analysis	Petri Nets
Collect Artifacts of Task Performance	Precursor, Action, Results, & Interpretation
Concept Mapping	Problem Analysis
Conceptual Graph Construction	Problem Discussion
Critical Decision Method	Protocol Analysis
Critical Incident Method	Proximity Scaling
Critiquing	Q Sort
Data Flow Modeling	Questionnaire
Decompose, Network, and Assess Method	Rapid Prototyping
Decision Analysis	Rating and Sorting Tasks
Diagramming	Reclassification
Discourse Analysis	Repertory Grid
Distinguishing Goals	Retrospective Case Description
Dividing the Domain	Role Playing
Document Analysis	Semantic Nets
Entity Life Modeling	Shadowing (Self/Others)
Entity-Relationship Modeling	Simulators and Mockups
Ethnographic Methods	Step Listing
Exploratory Sequential Data Analysis	Storyboarding
Field Observations	Structural Analysis Technique
Forward Scenario Simulation	Stumbling Block Technique
Goal Decomposition	System Examination
Goal Directed Task Analysis	System Refinement
Goals, Operators, Methods, Selection Rules	System Validation
Group Interview	Table-Top Analysis
Hierarchical Sort	Task Action Mapping
IDEF Modeling	Task Knowledge Structures
Influence Diagram Construction	Teachback
Interesting Cases	Think Aloud
Interruption Analysis	Tutorial Interview
Interviewing (Structured, Unstructured, Semi-Structured)	Twenty Questions
	Uncertain Information Elicitation
Laddered Grid	User Needs Analysis
Likert Scale Elicitation	Wizard of Oz Technique

Figure 2. Listing of Cognitive Task Analysis Methods.

With its concentration on non-observable cognitive processes, cognitive task analysis is more amenable to the investigation of future systems and processes. Specifically, those methods developed for the knowledge elicitation phase hold considerable promise for improving our ability to create new concepts and develop future systems. Components of various cognitive methods that extend traditional approaches for describing current systems, while not specifically designed for such purposes, can be used to systematically capture, analyze, test, and evaluate future constructs. The following section will provide more detail on knowledge elicitation techniques and methods.

Knowledge Elicitation

Knowledge elicitation methods are a key component of the information gathering stage of task or cognitive-task analysis – they provide the mechanism by which knowledge is transferred from the expert to the analyst. The methods attempt to provide a convenient way to accurately and easily allow experts to communicate their expertise. Despite the abundance of elicitation techniques available, capturing expert knowledge and understanding how the knowledge relates to problem solving capabilities remains an obstacle for expert system development (Moody, Blanton, & Will, 1998/1999). Often, the knowledge elicitation used to develop expert systems is vague or glossed over because it is largely ad hoc and non-scientific (Wright & Ayton, 1987). Klein, Calderwood, and MacGregor (1989a) point out a tendency to emphasize explicit knowledge (also called declarative knowledge) over implicit knowledge (also called tacit knowledge). Explicit knowledge is information that is easily accessed, expressed, stored, and applied. Implicit knowledge, on the other hand, is information that exists in the experts' unconscious and is not easily accessible. Experts, through years of practice, develop automatic habits that are characteristic of expert performance. These unconscious chunks of knowledge usually go to the heart of what makes someone an expert. Effective knowledge elicitation techniques for determining the unique contributions of both implicit and explicit knowledge should be used. Knowledge elicitation methods that overemphasize explicit knowledge lead to "the mistaken conclusion that explicit knowledge is sufficient for performing a task well" (Klein, et al., 1989a, p. 463).

The knowledge elicitation technique should provide the expert with an appropriate set of procedures for transferring information to the researcher or analyst. In planning knowledge elicitation, there are several decisions that must be made to ensure that the process is effective and the results are reliable and valid (Meyer & Booker, 1991). The researcher must determine the setting in which the expert judgment is to be gathered and select a form of communication for asking and answering questions. The elicitation technique chosen determines how the experts will respond and how their responses will be coded. Often it is important to allow future participants to 'see' the thought processes of previous experts. Finally, a method for aggregating responses from multiple experts into a single representation is needed for the researcher to communicate and describe the results.

Communication Techniques and Settings

The setting describes the arrangement of the meeting between researcher and experts. Several broad categories have been used to effectively elicit knowledge including private interviews, group interviews, interactive group discussions, and remote response reception.

These settings can be combined or modified as appropriate. The use of multiple settings may be especially important when collecting observations about future concepts and situations. Detailed tacit knowledge can be collected from an expert from a specific domain area during a private interview. Group interviews, however, allow an expert from one domain area to interact with experts from other domains. Combining the perspective from different domain areas may be critical for the analyst to truly understand goals, technological relationships, interconnections, and ideas concerning the future.

Private interviews should be semi-structured and can be used to develop initial concepts and ideas that are unimpeded by the inherent limitations of interactive groups. The results from the private interviews feed the interactive group discussions; including face-to-face meetings including two or more experts from multiple domain areas. The interactive group discussion technique originated in marketing as the focus group and can be either structured or unstructured. Meyer & Booker (1991) claim that interactive groups produce a larger amount of data with greater predictive value than do individual interviews or the Delphi method (described below) alone. Feedback from other participants stimulates conversation, resulting in deeper and richer data. A possible problem with this method is groupthink, a frequent tendency of groups to be less critical in their evaluation and not question poor decisions. Used in conjunction with personal interviews, the interactive group discussions allow expert participants to debate various topics and develop a consensus by aggregating results.

Elicitation Techniques

The selection of a knowledge elicitation method for a specific domain involves several considerations. Criteria for selection depend upon the researcher's level of familiarity with the domain and the amount of time and money required for the analysis. Knowledge elicitation methods are typically divided into two broad categories, direct and indirect. Direct methods involve the researcher asking domain experts to tell how they perform their job. Examples include the various forms of interviewing, protocol analysis, simulation, concept mapping, and the Critical Decision Method (CDM). The effectiveness of direct methods depends upon the articulation and cooperation of the experts and their ability to verbalize the information. Typically experts are easily able to verbalize declarative knowledge. Declarative knowledge, also called explicit knowledge, is represented by classifications and relationships. It focuses on descriptions of facts, things, methods, or procedures. Although facts and concepts can be expressed verbally, the interview process may not always yield patterns and structures discernable by the researcher (Evans, 1988).

Indirect methods are thought to be more suitable when knowledge is not easily expressed by the expert. Tacit knowledge, which has been learned implicitly through experience, and overlearned automatic procedural knowledge can often be difficult for experts to express. Indirect methods constrain the experts to state their knowledge with the help of predefined structures such as, repertory grids (Kelly, 1955; Gaines & Shaw, 1992), decision trees, card sorting (Geiwitz, Kornell, & McCloskey, 1990; Major, 1991), and laddering techniques (Geiwitz, et al., 1990; Rugg, Mcgeorge, & Shadbolt, 1990; Cordingley, 1989). It is worth noting, however, that direct methods such as CDM have also been used successfully to elicit tacit knowledge. In addition, indirect methods are capable of complementing direct methods.

Due to the complexity of most domain areas and the difficulties associated with forecasting future capabilities and requirements a combination of several methods should be employed to collect information from knowledgeable experts. The next sections will briefly highlight three of the most popular methods of knowledge elicitation. As with the review of cognitive task analysis, the review is not intended to be exhaustive. The intent is to provide an overview of a few of the most widely used methods which contribute to the development of a new method of elicitation focused on the elicitation of knowledge for use with future situations and concept development.

The Delphi Technique. The Delphi technique was originally developed by the RAND Corporation to provide a method to elicit expert knowledge and develop group consensus among participants (Dalkey, 1969). In traditional Delphi approaches, experts do not interact directly with one another and only interact with the researcher in a limited manner. The researcher gathers responses, makes them anonymous, and provides them to other expert participants. After reviewing the responses provided by other participants, each expert submits a revised response. The process is repeated as many times as necessary. The method was designed to avoid the groupthink bias of interactive groups. The objective of bias avoidance is met if, as experts revise their answers, they are converging on the correct answer. Difficulty arises in assessing the quality of the answer and, thus, whether groupthink existed in reaching consensus (Meyer & Booker, 1991). Traditionally, the Delphi method used the standard postal mail system to distribute and collect responses; now, however, electronic-mail is usually used instead.

Interviews. Interviewing involves the researcher asking the expert a series of questions such as to recall and describe the steps taken in performing a task. Sometimes the expert is asked to differentiate between or give examples of terms, concepts, or events. Interviews can be unstructured, structured, or semi-structured. In unstructured interviews, the researcher asks open-ended questions about the expert's reasoning in making decisions and records the responses. This interview method allows the researcher to become familiar with jargon and gain an overview of the domain. The major disadvantage of unstructured interviews is that disorder can ensue if the expert speaks off topic or erroneously assumes that the researcher is knowledgeable in the domain (Hoffman, Shadbolt, Burton, & Klein, 1995). Structured interviews are preplanned to reduce the time length of the interviewing process by focusing the expert only on specific questions. Planning structured interviews requires that the researcher possess some knowledge of the domain. Semi-structured interviews are often the preferred style as they allow the researcher to add questions to clarify points and to omit questions that become redundant or irrelevant as the interview evolves. The technique promotes more continuity in the data than unstructured interviews. Continuity assists in the comparison and aggregation of responses from various experts. By asking the expert to explain the rationale or assumptions of the response, researchers ensure that each expert is responding to the same question. Compared to structured and unstructured interviews, semi-structured interviews are more likely to produce data that is germane without the inefficiencies of collecting unnecessary data (Meyer & Booker, 1991).

Protocol Analysis. Protocol analysis involves the researcher recording the expert as the task is completed. Asking the expert to actually perform tasks will often generate more valid knowledge than asking experts to simply describe the steps required by asking probing questions

(Wright & Ayton, 1987). In addition, the expert is required to 'think aloud' while working through the problem or situation. The purpose is to identify knowledge elements and steps required for problem solving in the given domain area. The method has the advantage of allowing the expert to perform the task in a work context while verbalizing the cognitive activities required for success. One limitation of the method is that it is based on introspection and bias to the problem-solving processes (Wright & Ayton, 1987). If the task is one that can be performed automatically, then experts are often able to introspect while they perform. If, however, the task has a substantial cognitive component, the think aloud requirement may interfere with task performance. However, this limitation can be negated by video recording the expert during task performance and replaying the video during an interview session. This process is called retrospective protocol analysis and improves the amount and quality of tacit knowledge elicited.

Knowledge Creation

To create reliable knowledge it is not sufficient to elicit information from a group of domain area experts, it is necessary to prod them to go beyond what they already know. When developing concepts about the future, researchers should conduct a thorough review of current trends. Three methods are useful in this regard: environmental scanning, backcasting, and technological forecasting. The methods produce insights that guide decision making and are invaluable to the development of realistic scenarios that can be used to elicit knowledge and develop new concepts.

Environmental Scanning

In order to reliably investigate future issues and scenarios, a firm understanding of the current environment is needed. Environmental scanning is a systematic method of accomplishing this. In this context, environmental scanning is defined as the acquisition, compilation, synthesis, analysis, and utilization of information, knowledge, trends, and relationships concerning the internal and external environment which would assist in selecting, planning, and implementing a realistic course of action (Aguilar, 1967). Coates (1985) describes the objectives of environmental scanning as: detecting scientific, technical, social, political, and economic trends relevant to the problem under investigation, defining potential threats, opportunities, and challenges implied by those trends, enhancing future-focused thinking, and identifying trends that are converging, diverging, impending, distant, or interacting.

Technological Forecasting

Technology is often a key driver in the development of any new product or system. This is particularly the case where military systems are concerned. The ability to accurately predict the availability of a given technology will have a critical impact on the success of a given program, project, or system. Technological forecasting, as the name suggests, is interested in forecasting the types of technologies that will be available in a future time period, the characteristics of those technologies, and a realistic estimate of their availability.

There are two primary methods of technological forecasting: ontological view and teleological view (Frick, 1974). The ontological view assumes that technological change and innovation are the result of scientific and technical opportunities and advancement. The teleological view assumes that technology change and innovation are the result of environmental factors (i.e., social, economic, political, etc.) that demand a desired end result. Thus, technological forecasting methods can be classified as exploratory (ontological view) or normative (teleological view). Frick (1974) characterized the methods by stating that one could think of exploratory and normative forecasting as analysis according to the 'push' of opportunities versus the 'pull' of objectives. Exploratory methods include: economic analysis, extrapolation of time-series, learning curves, trend analysis, morphological systematic exploration, probabilistic exploratory forecasting, qualitative historical analogy, and time-independent contextual mapping (Jantsch, 1967; Frick, 1974). Normative forecasting methods include: morphological analysis (schematic and matrix), relevance trees, mission flow, decision matrices, and systems analysis.

Traditionally, technological forecasting was centered on the estimates by recognized experts. Those estimates may no longer be as appropriate since technological advancement and progress has become increasingly more dependent on the unique contributions of several diverse technologies (Meredith & Mantel, 2004). Meredith and Mantel (2004) also point out that the degree and speed of technological advancement and change is related to the funding of several unique technologies. Therefore, in order to reliably forecast the availability of future technological systems it is necessary to elicit knowledge from a range of experts on a number of relevant topics.

One final point about technological forecasting is relevant to the current discussion. The fact that technological advancement results in a new capability does not mean that it will be or should be put to immediate use. The introduction of new technology or technological systems does not affect a single variable – it affects and transforms the entire system, transforming roles, judgments, goals, and relationships (Carroll & Rosson, 1992). The successful application and implementation of a new technological innovation often does not occur until five to seven years after the discovery (Rosegger, 1986). It takes a fair amount of time to understand how to most effectively and efficiently implement a technology while understanding the effect on the overall system and organization. As Harville (2004) suggested, "it is also possible … to pour resources into developing a new technology too soon, so that the effort is largely wasted and futile" (p. 1).

Backcasting

Environmental scanning focuses on identifying information about the environment, including the current state-of-the-art and likely technological advancements. Backcasting is an extension of an environmental scan to identify what the desired future should look like. This is in contrast to forecasting, which attempts to predict the future. As Hojer & Mattson (1999) suggest, "forecasting, based more or less on prolonging existing trends, is of little value beyond the role of an alarm-clock" (p. 10).

Backcasting is an extension of a thorough and reliable forecast that begins with a desirable future endstate (Robinson, 1982). Once the endstate or desirable future has been identified, the backcast works backwards to determine what reasonable steps must be accomplished to reach the endstate through visionary thinking. The backcast should include "what-if" analysis to identify conditions and risks to meeting the objective. Thus, the backcast can help identify the “technological leaps” required to reach the endstate. The backcasting approach consist of six steps: determine the objectives, specify the goals, constraints, and targets, describe current state, specify exogenous variable, complete scenario analysis, and complete impact analysis (Robinson, 1990).

Enabling Knowledge Creation

When looking at future issues, especially issues that are five to ten or more years out, it is necessary to move from elicitation of existing knowledge to the creation of new knowledge. While current techniques of cognitive task analysis and knowledge elicitation provide a mechanism for acquiring existing knowledge they are not designed for predicting and assessing realistic observations and concepts about the future. Effective methods are needed for capturing knowledge from available information sources and using that knowledge to create new ideas and concepts.

Based on the distinction between explicit and tacit knowledge, Nonaka & Takeuchi (1995) present a model for knowledge creation and conversion. Figure 3 reproduces the four patterns of interaction between explicit and tacit knowledge outlined by Nonaka & Takeuchi, 1995). The four quadrants characterize the ways in which knowledge can be converted into new concepts and ideas. The authors assert that tacit knowledge can be converted into new tacit knowledge through the process of socialization – the sharing of experiences, metal models, and technical skills. Tacit knowledge can be converted into new explicit knowledge through the process of externalization – where experts interact with novices and transfer information using metaphors, analogies, and models. Explicit knowledge is converted to tacit knowledge through the process of internalization, thought experimentation, and individual learning. Finally, explicit knowledge can be converted to new explicit knowledge through the process of combination. In combination, new knowledge is created by reconfiguring existing knowledge through sorting, recategorizing, or other methods to expand the understanding of existing concepts.

From \ To	Tacit Knowledge	Explicit Knowledge
Tacit Knowledge	Socialization	Externalization
Explicit Knowledge	Internalization	Combination

Figure 3. Development Process for New Knowledge and Concepts.

In sum, knowledge creation is a continuous process for transferring and sharing tacit and explicit knowledge with groups and individuals (Bloodgood & Salisbury, 2001). The knowledge creation process results in the development of principles, facts, concepts, procedures, and processes – these products must be extended to develop future concepts. The modes of knowledge creation described by Nonaka & Takeuchi seem most appropriate when transferring or transforming existing knowledge within a relatively stable system, but not necessarily development and synthesis of unique, unknown concepts and ideas for a U.S. Army future environment that is changing rapidly. Figure 4 illustrates an expansion of the process to include the development of new concepts. The critical step is expanding the methodology to create unique knowledge.

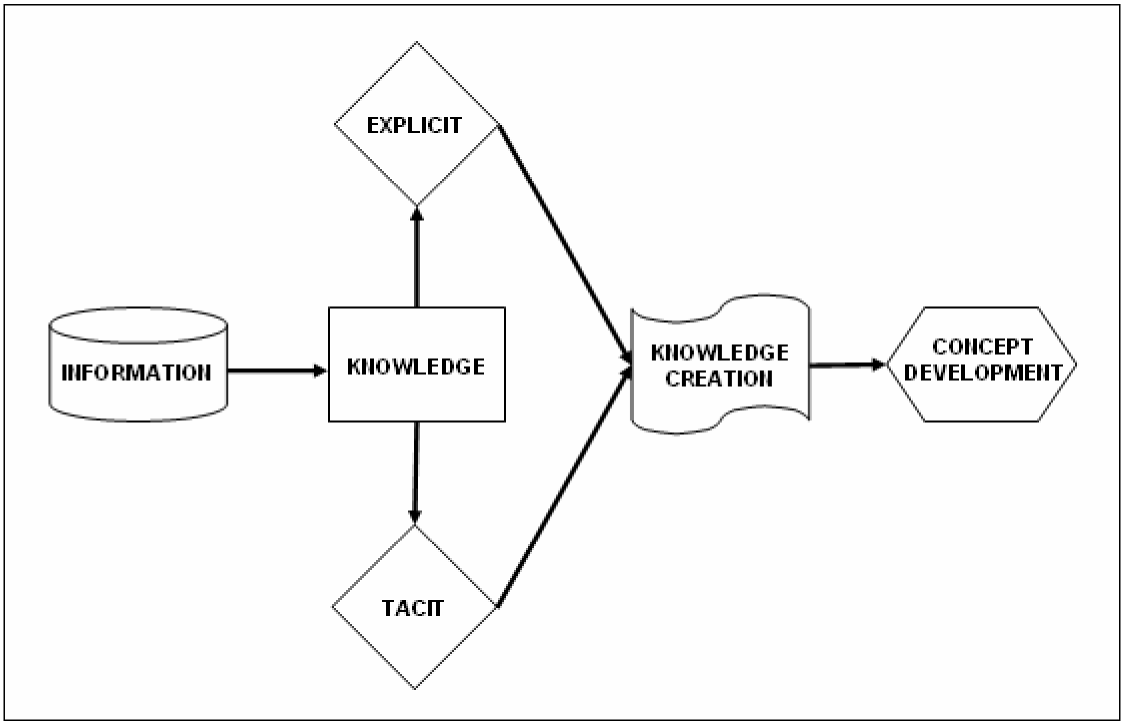

Figure 4. Concept Development Process.

A New Method

While the methods described above provide a number of capabilities, they do not provide a useful or suitable process for the development and evaluation of new knowledge and concepts about the future. A new method is needed to address the unique aspects associated with the development of new concepts and prediction of future realities. This section will describe such a method, the Flexible Method of Cognitive Task Analysis (FLEX).

Although the FLEX method shares many features with other methods of analysis it offers many components that differentiate it from traditional methods of cognitive task analysis and knowledge elicitation. Specifically, it focuses on the development and evaluation of future knowledge. The FLEX attempts to be more comprehensive than conventional cognitive task analysis methods by attempting to capture not only traditional task information but also to provide a methodology that can capture the conglomerate of interdependent and dynamic knowledge sources. The method allows researchers to capture existing knowledge and it facilitates the creation of new knowledge and concepts. The technique is similar to the information acceleration method used in the marketing domain. In the information acceleration method where companies try to forecast consumers' response to new products by providing early models to focus groups.

The FLEX method is an interview-based problem solving approach that systematically develops and explores future concepts. The approach uses a combination of the Critical Decision Method, Protocol Analysis, the Delphi technique, and the standard interview. Unlike existing methods, the FLEX method grounds the experts thinking in a futuristic setting. Thus, knowledge will be captured by employing a vignette-based scenario approach where experts are provided with a brief multimedia presentation that highlights a potential future situation and requires the expert to solve a complex problem using the anticipated capabilities. To do so, experts are required to figure out how to solve the issues presented in the scenario using the resources and capabilities provided.

Similar to protocol analysis, participants are asked to verbalize their responses by thinking aloud. However, similar to the Delphi technique, responses from each participant are provided to subsequent participants. Therefore, subsequent participants are able to identify weaknesses, confirm strengths, and build upon the prior responses. Throughout the process, a semi-structured interview is used to probe expert knowledge and gain a deeper understanding of the expert's reasoning. Before the completion of the process, responses from subsequent participants are fed back to the originator for additional input. Finally, a small group of experts are used for interactive group discussions allowing for consensus building and validation.

The vignette-based, scenario approach is appropriate in this context because it is often difficult for individuals to speculate on how future capabilities might be employed. Further, many experts tend to over-estimate the impact of future technological advances and to ignore the difficulties. Thus, forcing the participants to solve a concrete problem helps ground their thinking so that more appropriate and realistic information can be captured. Figure 5 illustrates how the flex process produces future tactics, techniques, and procedures (TTP), concepts, and other products. The following section summarizes the steps involved in developing a FLEX scenario and conducting a knowledge elicitation and concept exercise.

Phase 1: Domain and Problem Identification

In the first phase of the FLEX approach, it is necessary to define the domain area and identify the significant problems of interest. Defining the domain will help specify the scope of the information that will be needed and will assist in the identification of experts. Since a goal of the method is not only to capture new knowledge but to systematically investigate the efficacy of the information collected, the identification of a significant number of appropriate experts is required. In most cases, a diverse set of experts will be required from a variety of technical fields – particularly in cases where technological advancements are expected to play a critical role in the development of new systems and processes. During the problem identification phase, an environmental scan, backcast, and/or technological forecast should be conducted to assist in understanding the potential for technological innovation and advancement.

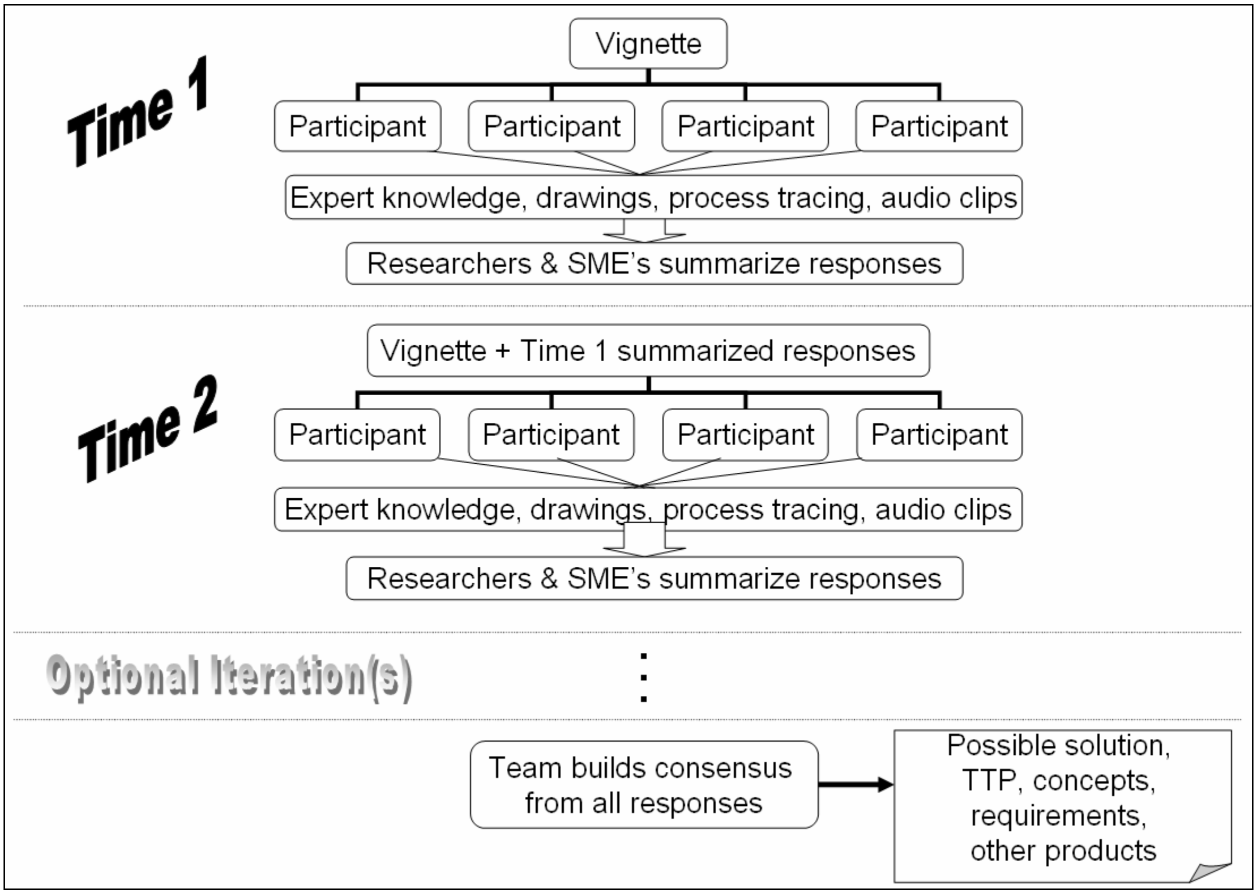

Figure 5. Overview of the FLEX Process.

Phase 2: Initial Review and Analysis

During the initial review and analysis it is important to capture information concerning the current state-of-the-art for the domain and problem space. This phase is similar to what would be expected during traditional task analysis – both procedural and cognitive. During the initial review it is necessary to interview experts, document current processes, and gather information about expert performance. Contrary to traditional task analysis, the goal is not to develop a complete list of tasks and duties in a given domain. The goal is to gain an understanding of domain expertise, task requirements, processes, and outcomes. During the review it is critical to identify areas where innovation may lead to improved performance and processes and to gain an understanding of current research and immediate technological innovation for the domain.

Phase 3: Refine Problem Space and Develop Initial Scenario

During this phase, initial decisions regarding the knowledge elicitation scenario should be established. An initial group of domain experts should be used to develop one or more scenarios with appropriate "branches." The branches should represent contentious areas where multiple realities are possible. The scenarios should be developed in an iterative fashion, allowing experts to develop a realistic situation capable of focusing the knowledge elicitation process. At this stage, it is not necessary to fully develop the situation – it is only necessary to establish the initial conditions for the knowledge elicitation process.

Phase 4: Initial Knowledge Elicitation

Based on the scenario, this phase should elicit knowledge and concepts from a series of experts from the relevant domain areas. The scenario should be used as a starting point to focus the experts on a particular problem area. The elicitation process should allow the experts to further refine the scenario by adding new information, challenging existing assumptions, anticipate unintended consequences, and predicting technological interventions. During the elicitation, experts should be asked to discover new ways to solve problems associated with the scenario given hypothesized future capabilities. Knowledge elicitation should focus on both individuals and small groups (e.g., dyads, triads) and should combine experts from different specialty areas.

Phase 5: Data Reduction and Consensus Building

After a sufficient sample of experts have had the opportunity to complete the knowledge elicitation phases, it is necessary to aggregate the data into common and meaningful responses. The data reduction phase should allow a small group of experts, a different group from phase 4, to develop a consensus on the efficacy of the new knowledge and concepts captured from phase 4. The information can then be used to update the scenario to reflect the new knowledge stream or create a new branch to highlight "what if" situations. The altering of the scenario allows the experts to "leave their fingerprints" on the scenario and allows an iterative process for continuous improvement.

After revising the scenario based on the initial knowledge elicitation and data reduction phases, it is necessary to reexamine the scenario with a new set of experts and provide the revised materials to former participants. This process provides a systematic way to evaluate the realism of the new information. Thus, Phases 4 and 5 may be repeated several times until a tested solution is developed. The goal of the iterative process is to develop a well tested and documented solution for the purpose of developing new theories, principles, tools, techniques, and procedures.

Phase 6: Knowledge Representation and Concept Documentation

Knowledge representation provides a mechanism for documenting and displaying information in a useable format. In this context, knowledge refers to organized concepts, theories, principles, descriptions, and mental models of descriptive, procedural, and meta-cognitive information. The goal is to present the results of the knowledge elicitation process in a meaningful way. Knowledge can be represented using a variety of methods, including: logic, semantic networks, production rules, frame-based representations, decision trees, graphs, diagrams, charts, and tables.

Using Experts for Knowledge Elicitation and Creation

The previous sections of this document have outlined the use of experts to elicit knowledge about a particular task or domain area. Expertise is highly specific to a particular domain. Cognitive performance is interrelated to domain content and context (Newell & Simon, 1972). In other words, experts in one domain area may be novices in a different area.

Experts are bound by their history and experience and not all experts are able to reason beyond the information and knowledge readily available in their environment. When confronted with a new problem, experts call upon their prior knowledge and experiences in order to solve the problem or predict future events. There is no guarantee that an expert in an existing domain area will continue to be an expert in a future realization of that domain. In research leading to the development of the FLEX method, some of the military subject matter experts who served as participants were unable to free their thinking from current doctrine. Furthermore, some who have spent time studying the Army's emerging future force doctrinal concepts had difficulty critically evaluating those concepts. Other participants, however, were stimulated by the FLEX method to provide extremely unique, creative, and well-reasoned responses (Gossman, Mauzy, Heiden, & Flynn, in preparation). It did not seem to the researchers that expertise in current operations was a good predictor of how successful the participant would be. Consider the difficulty administrative assistants, experts in using typewriters, had adapting to the introduction of computers to the workplace. Yet, these experts will ultimately contribute to and influence the decision making process (Karat, Karat, & Vergo, 2004) regarding future systems.

Often it is assumed that a domain's most experienced individuals are also the ones with the most expertise. Several research studies have questioned the accuracy this assumption (e.g., Jacob, Lys, & Neale, 1997; Camerer & Johnson, 1991). Many of these studies led Ericsson (2000) to suggest, ". . . continued improvements (changes) in achievement are not automatic consequences of more experience and in those domains where performance consistently increases aspiring experts seek out particular kinds of experience, that is deliberate practice." While experience is often used as an indicator of expertise (e.g., hours of flying time) especially when more objective measures are lacking, it tends to be inadequate. Experience may be necessary for expertise, but experience is not, in and of itself, sufficient in the development of expertise (Rohrbaugh & Shanteau, 1999).

Even if true experts are identified there is a concern that their knowledge may be biased. With specific attention to forecasting future technologies, Tichy (2002) stated, "top experts . . . demand a more active policy to promote their field of work and tend to be overoptimistic with regard to the realization of innovations" (p. 19). The over-optimism bias is most notably expressed in terms of innovativeness of the technology, the chance of realizing the technology, and the potential exploitation of the technology. These findings led the author to conclude that "foresight exercises should include not only top experts of the relevant field, but also experts with a broader range of interest as well as experts with widely differing backgrounds" (p. 4). The failure to select the right group of experts in concept development exercises "is likely to bring assessments that are too optimistic" (Tichy, 2002, p. 19). In the Army transformation planning effort, in particular the development of Future Combat Systems, initial plans were very optimistic and remain so despite several reductions in requirements and increases in timelines.

The question remains then, how do we identify and select participants for an elicitation exercise? It is necessary to select experts that are capable of extending their knowledge, mental models, and schemas beyond their current state in a reliable and valid way. The research on identifying appropriate experts, much less identifying those experts capable of extending their knowledge to future concepts, is relatively absent. As Subramani, Peddibhotla, and Curley (2003) suggested, "Given the importance of the issue, it is surprising that it has received little attention in prior research" (p. 4).

Bloom's (1956) taxonomy provides a potential starting point to developing a systematic methodology for accurately selecting experts. The taxonomy consists of six categories (knowledge, comprehension, application, analysis, synthesis, and evaluation) of higher-order cognitive thinking skills. Figure 6 illustrates the taxonomy and highlights the abilities of experts in each category. Experts at the synthesis and evaluation level may have the required abilities to examine future issues and develop new knowledge and concepts. These abilities include the ability to role-play, invent, speculate, and develop information (synthesis). Additionally, these individuals are able to compare, judge, critique, and assess concepts, and can make conclusions and recommendations based on information.

Clearly, identifying appropriate experts for an elicitation exercise is the most important component of the process. Future research efforts must focus on developing techniques and procedures for addressing the issue.

Conclusions

Potter, Roth, Woods, and Elm (2000) stated, "in performing cognitive task analysis, it is important to utilize a balanced suite of methods that enable both the demands of the domain and the knowledge and strategies of domain expertise to be captured in a way that enables a clear identification of opportunities for improved support" (p. 321). There is clearly a need for a systematic approach to eliciting information needed to develop future concepts, processes, systems, and procedures. The method described here provides a flexible method for eliciting and creating concepts and information for investigating, creating, testing, and understanding future issues. Ongoing efforts, such as the U.S Army Research Institute's project to develop training for crisis action planning and execution (Beaubien, 2005), are using the method to evaluate its effectiveness.

In concluding this analysis it is important to restate one of our original questions: How do we best use the total Army team – warfighter, scientist, theorist, analyst, and engineer – in the development process of future concepts? Diaper & Stanton (2004) stated that, "Task analysis without psychology is like peaches and cream without the peaches: thin stuff" (p. 567). The same can be stated about the warfighter, theorist, analysis, or engineer. The Army can no longer rely on haphazard or unsystematic methods for concept development that do not include the total Army team. Therefore, the critical need is to implement a process that systematically allows for effective and efficient management of the concept development process. The FLEX method represents an attempt to integrate and exploit the capabilities of the total Army team.

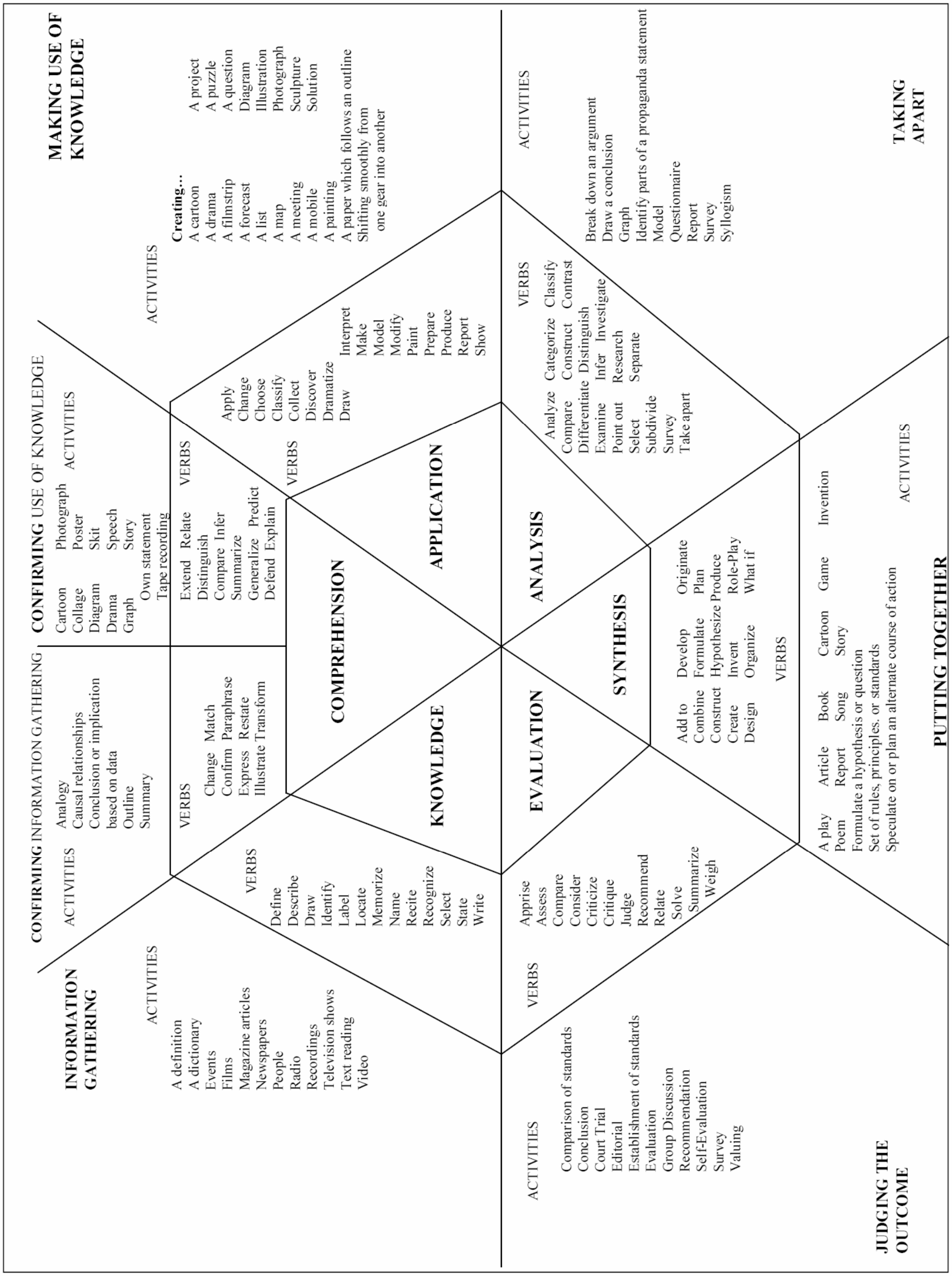

Figure 6. Task Oriented Question Construction Wheel Based on Bloom's Taxonomy, © 2004 St. Edward's University Center for Teaching Excellence.

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Appendix A

Applied Cognitive Task Analysis

A widely used approach to cognitive task analysis is Applied Cognitive Task Analysis (ACTA). The ACTA method is designed to provide streamlined techniques to elicit and capture the cognitive aspects of expert performance (Militello, Hutton, Pliske, Knight, & Klein, 1997). The intent was to develop tools that were easier to use than the methods of cognitive task analysis available at the time the method was developed. The method consists of three complementary techniques (task diagram, knowledge audit, and simulation interview) used to elicit different aspects of cognitive performance for a given task. The objective of the task diagram is to provide the analyst with a general overview of the domain area and to highlight the cognitively demanding portions of the task. The knowledge audit is used to further investigate the specific expertise required for a particular task or subtask. Finally, the simulation interview uses a scenario to probe the cognitive processes involved in a specific situation. The results of each of the techniques are consolidated in a cognitive demands table used to synthesize the data so that it can be applied to a specific situation or project. The ACTA method was developed to assist instructional designers and training professionals in developing training that focuses on cognitive skills.

Critical Decision Method

Using the Critical Incident Technique originally modeled by Flanagan (1954), Klein, Calderwood, and MacGregor (1989b) developed a technique called Critical Decision Method (CDM). The premise of the CDM is that useful information can be retrieved by having experts recall a salient incident or cases. In most situations, the case identified represents a non-routine incident where expert performance can be highlighted. The incident becomes the focus of a semi-structured interview where cognitive probes are used to understand the expert's situation assessment and decision making.

There are several advantages to CDM. The semi-structured format is flexible, allowing the interviewer to switch to more relevant issues as the dialogue progresses. Focusing on critical incidents highlights the very capabilities that separate experts from novices allowing little time to be wasted on general tasks that do not require the specialized skill of the expert. Probed recall of such tough cases is effective in revealing previously inaccessible knowledge of highly skilled personnel. As Klein, Calderwood, & Macgregor (1989b) state, "the focus on non-routine cases also makes the method most appropriate to eliciting tacit knowledge that is not part of the formalized procedures for a domain" (p. 465). The categorization of CDM as a specific type of technique is not definitive because the technique incorporates aspects of several other knowledge elicitation methods. Klein (1996) stated that, "the CDM is a protocol analysis method" (p. 4). However, CDM lacks the 'think aloud' aspect of standard protocol analysis and focuses on a prior event, rather than a current or future problem. It is similar to a case study in that a scenario is analyzed from a decision making perspective, but in CDM the expert actually experienced the case firsthand.

Precursor, Action, Results, Interpretation (PARI)

The PARI technique (Hall, Gott, & Pokomy, 1995) is a specialized interview technique that combines the technique of thinking aloud described by Ericsson and Simon (1993) with expert and novice problem solving activity (Gott, 1998). The Precursor, Action, Results, Interpretation (PARI) procedure utilizes a "situated problem-solving session" where experts demonstrate their knowledge based on a specific problem or context while being probed through structured questioning to elicit knowledge and expert skills. The approach attempts to identify the action a performer would take given a specific precursor event, the result the action would have initiated, and the performer's interpretation of the result. The approach further defines the cognitive process by allowing the performers to document their internal mental models.

Decompose, Network, and Assess Method (DNA)

The DNA method was developed to provide a practical approach to cognitive task analysis that was capable of eliciting and capturing task information from experts and novices across a wide range of domain areas (Shute & Torreano, 1995). The DNA method is supported with software tools that attempt to automate the knowledge elicitation, knowledge organization, and management, and hierarchically structure knowledge for the given domain. Shute, Torreano, and Willis (1999) describe the DNA as a method to "elicit knowledge from subject-matter experts which will Decompose a domain, Network the knowledge into comprehensive structures, and employ other experts in a given domain to Assess the validity, completeness, and reliability of the knowledge structures" (p. 369).

The method and software consist of four modules (Customize, Decompose, Network, and Assess). The customize module is used to provide the analyst with a means to provide specific information about the domain area. The decompose module operates as an interactive, semi-structured interview and is used to elicit procedural and conceptual domain knowledge from subject-matter experts. The intent of the network module is to transform expert knowledge into knowledge hierarchies, graphs, and rules. The assess module is used to validate the information acquired and products developed during the elicitation process. Here, multiple experts are "employed to review and edit one another's conceptual graphs as a method of validating externalized knowledge structures" (Shute, Torreano, & Willis, 1999, p. 375).

Task Knowledge Structures (TKS)

The TKS method was derived from work by Johnson, Diaper, and Long (1984) on Task Analysis for Knowledge Descriptions and attempts to identify the various aspects of knowledge and information requirements for a task. The TKS method characterizes the knowledge of subject-matter experts based on previous experiences. A major assumption of TKS is that during the development of expertise individuals develop specific knowledge structures (Hamilton, 1996) that are represented in memory (Johnson & Johnson, 1991). The TKS method provides a mechanism for collecting information about how experts perform required tasks and consists of two separate components, a goal structure and a taxonomic structure. The goal structure identifies the task activities, goals, subgoals, and provides an understanding of the steps needed to complete the task. The taxonomic structure includes information about actions and objects, including their classification, attributes, relationships to one another, features, and typicality rating (Johnson & Johnson, 1991). The TKS method assumes that the task knowledge is structured in a meaningful way and can be analyzed, modeled, and predicted.

Goals, Operators, Methods, Selection Rules (GOMS)

The GOMS method (Card, Moran, & Newell, 1983) is a cognitive task analysis and modeling method that has been used extensively in the analysis of human-computer-interactions to document expert performance models. The approach is composed of four parts: goals, operators, methods, and selection rules. Goals are considered to be the endstate of the task when successfully completed – what the user wants to achieve. Operators are the procedural, perceptual, psychomotor, and cognitive actions that must be taken to accomplish the various goals and subgoals. The operators are sequenced to develop the methods or the specific step-by-step procedures for accomplishing the tasks. Operators are assigned an execution time represented the average amount of time required to complete the steps. Selection rules consist of the "if-then" decision rules and conditions that experts used to determine which method should be used to complete a particular goal or subgoal.

The GOMS method is based on the assumption that experts interacting with a system are involved in problem solving. By analyzing how experts interact with the system it is possible to decompose the task or problem into subproblems and an understanding of the goals and expectations can be developed allowing for a logical sequence of operations and timing values for each operation to be documented. The model also provides a mechanism for making predications about how experts will perform given a proposed design. The method is not well suited for complex cognitive skills or for use with novices. However, there have been several variants to the GOMS method to address many of the methods shortcomings. The Natural Goals, Operators, Methods, and Selection Rules Language (NGOMS, Kieras, 1988) method, for example, added a mechanism to deal with expert-novice differences.

Goal-Directed Task Analysis (GDTA)

The GDTA method is a cognitive task analysis technique that concentrates on identifying an expert's situational awareness needs and requirements for a particular task (Endsley, 1993). Endsley (2000) defined situational awareness as those "dynamic information needs associated with the major goals or subgoals of the operator in performing his or her job (as opposed to more static knowledge such as rules, procedures, and general system knowledge" (p. 149). Situational awareness requirements can be described by three levels of awareness. Level 1 Situational Awareness – Perception, involves the perception and identification of significant factors in the environment. Level 2 Situational Awareness – Comprehension, requires the expert or operator to interpret, store, retain, integrate multiple pieces of information, and understand the relevance to obtaining a particular goal. Level 3 Situational Awareness – Projection requires the ability to predict future events – the highest level of awareness.

Thus, the GDTA method systematically identifies the situational requirements needed for effective decision making. The actual analysis is conducted using a mixture of approaches, including: observation, verbal protocol analysis, questionnaires, analysis of written materials, and various knowledge elicitation techniques. The GDTA method has been successfully applied to a wide variety of domains (Endsley, 1999).