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Eliciting Knowledge from Military Ground Navigators

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Abstract: The N.D.M. framework is appropriate for the study of military ground navigators. Our characterization of expertise evolved from initial group to subsequent individual interviews. We describe our application of the C.D.M. to this domain and present the resulting Cue Inventory, Situation Assessment Record and Key Decision Requirements. We expose and discuss the dynamics of organization and methods we faced while gaining access to the participant community and conducting the study. The immediate goal is to apply the results to the development of navigation training interventions, so we conclude by discussing representations of navigation expertise that are suited for such applications.

1.0 Introduction

The purpose of this paper is to communicate what we have learned about tactical land navigation from our study of expert navigators. Over the course of this project, we discovered the Naturalistic Decision Making (N.D.M.) framework and immediately valued its relevance to our efforts (Klein, Orasanu, Calderwood & Zsambok, 1993; Orasanu & Connolly, 1993; Zsambok, 1997). Still, in the literature we found only a handful of case studies (Brezovic, Klein, & Thordsen, 1990; Flin, Slaven, & Stewart, 1996) to guide us through the mechanics of actually applying the N.D.M. framework to the conduct a cognitive task analysis of an actual domain. As pointed out by Hoffman, Crandall, & Shadbolt (1998), there is a lack of evaluative data in the literature, partially caused by a lack of publicly available methodological descriptions. This paper marks our contribution to help remedy that.

Before we launch into the three areas of discussion, we pause to briefly describe our motivation. Spatial awareness of environments and navigation skills are both essential to task performance and particularly difficult to acquire in many military domains. Past and current members of our research group have investigated the potential use of computer-based simulations and virtual environments to enhance the acquisition of navigation skill in two primary domains - helicopter piloting and dismounted infantry navigating (Darken & Banker, 1998; Goerger, 1998; Jones, 1999; Sullivan, Darken & McLean, 1998). Our students are military officers who, as leaders of units, wrestle with the challenges associated with training skills such as navigation. From this perspective, they recognize the deficiencies of current training approaches and opportunities for applying computer mediated interventions.

The origin of the current effort is a shared vision in which we supplement, not replace, traditional, physical navigation practice with targeted virtual environment practice sessions. One version of such a virtual training system incorporates a virtual, computer-generated expert navigator, who provides feedback to the student while practicing in the virtual environment. This system requires an executable model of expertise to drive the feedback module; this executable model was the initial goal of our knowledge elicitation and representation efforts.

We identify three areas that will be most valuable to readers interested in conducting Cognitive Task Analyses to support training. First, we describe the knowledge elicitation method we used. Through this description, we attempt to document a case study that may benefit others who plan to elicit knowledge in domains that share characteristics of the land navigation task, its operational environment and the dismounted infantry community. In this way, we contribute our experience to a small number of related infantry navigation studies (DuBois & Shalin, 1995; Ellis & Davidi, 1999; Klein & Wiggins, 1999).

Second, we represent the product of our knowledge elicitation. This representation serves to both describe domain expertise and expose the chosen representational formats for review. Finally, the ultimate purpose of this project is to consider ways to improve the ways navigators become competent, proficient and expert (Dreyfus, 1997). So, we conclude with a discussion about how our current knowledge elicitation and representation efforts have affected our future plans.

2.0 The Knowledge Elicitation Method

We were attracted to N.D.M. because it respected the influence of the environment on performance and emphasized study of performance out in the field, in the environment in which it naturally takes place (Zsambok, 1997). Furthermore, the N.D.M. framework emerged from inquiry into domains that were rather impervious to more traditional methods (Orasanu & Connolly, 1993; Zsambok, 1997). The profile of such domains defines properties of task and environment: the task is performed in dynamic, uncertain environments; the performer has to adapt to shifting, ill-defined, competing sub-goals; the performer must continuously monitor and integrate environmental feedback from his or her actions; the performance conditions are high-tempo and high-stress; there are high stakes placed on performance quality; there are multiple players involved; and there are organizational goals and norms (Orasanu & Connolly, 1993; Zsambok, 1997). These properties matched our domain properties quite closely.

After determining that expert infantry navigators could be found there, we conducted knowledge elicitation of students in the U.S. Army Special Forces School, located at Fort Bragg, North Carolina. We selected the Critical Decision Method (C.D.M.) to guide our knowledge elicitation (Hoffman, et al., 1998; Klein, Calderwood, & MacGregor, 1989). Our reasons for initially selecting the C.D.M. are closely aligned with the reasons Klein, Calderwood and MacGregor developed it (1989). We wanted to study the skill in its natural setting but could not justify the intrusion of direct observation methods.

We interviewed each expert immediately upon his completion of the specific patrol, typically within an hour of its completion. Our two-member team planned to conduct each individual interview within seventy-five minutes, but actual times varied between forty-five and sixty minutes each. Altogether, we held eight interviews. The first six were conducted indoors and the last two were done at night, in the field. The planned elicitation protocol closely matched that protocol described by Hoffman et al. (1998): 1. The interviewer orients participant to the patrol just completed as the patrol of interest. 2. The expert recounts the entire patrol. 3. The interviewer retells the story back to the expert. 4. The interviewer and expert collaborate to create a mission sketch and a time line. 5. The interviewer asks probe questions to deepen his understanding of the expert's mental processes.

These interviews mark our initial attempt at using the C.D.M., and we are quite pleased by the healthy amount of quality data elicited. Still, we are convinced that we could refine and revise our implementation of the C.D.M. to probe more deeply. Specifically, we are interested to learn more about group dynamics and interactions, different strategies used in different terrain environments and different conditions of limited visibility, the composition of the route descriptions and mental maps, and the nature of the anomalies that cue experts to catch their own errors. Whether or not the C.D.M. is the most appropriate tool for tapping these kinds of knowledge remains to be seen.

2.1 Lessons Learned

Before we discuss our critique, we must note that as powerful as the C.D.M. is, we must consider its value for knowledge elicitation in this particular domain. The nature of the domain skill and our research objectives may not be suited for this method. So far, we think it is suitable, but we are still evaluating it. Our critique of the method we used yielded many lessons learned, and we can group them into five categories: we learned about the culture, our planning of the interviews, the tools we used during the interviews, our conduct of the sessions, and the setting in which we conducted the interviews.

2.1.1 Culture

Members of our elicitation team have experience in the domain, and we thought we were representative of the domain population culture. We expected the infantrymen to enthusiastically accept and support our mission. Indeed, the interviewees were extremely motivated and cooperative during the interviews. Still, informal conversations with some interviewees and other members of the community revealed an overall skepticism about our objective. Our interpretations of the prevailing cultural beliefs follow: good navigators are not born, they are trained; expert navigators have paid their dues over years of experience, sweating and learning in the field; there is no shortcut, secret or mystery. Furthermore, it seems that the school itself does an excellent job of training its students. By the time the student reaches the patrol phase of the school, he has been exposed to a superior navigational training program, hence there is no urgent requirement for training enhancements at this school. We have yet to determine the accuracy of our interpretation nor if this situation is representative of other infantry units.

2.1.2 Tools

We intended to generate two artifacts during each interview. The first was the participant's sketch of the patrol; the second was a timeline, with key decision points indicated on it. After attempts to produce both artifacts, we dropped the timeline and focused effort on the patrol sketch. We found the sketch to be a good tool for investigating the travel phase but not for the planning phase. It seems that the sketch afforded a focal object for the discussion, while the timeline served to scatter the discussion too much. We may consider creating a new tool to facilitate discussions of planning issues. We created a timeline for each interview by ourselves after the interview, so we must figure out a way to incorporate its creation into the interview session itself.

2.1.3 Planning

Per the definition of the C.D.M., we want to identify decisions that truly are critical. We benefited basing our interviews on recently completed decisions, but we did not verify that for the interviewee this particular patrol "presented a unique level of challenge…" (Klein, et al., 1989). Also, if we were able to spend more time with each expert during the single or multiple sessions, we might have probed more deeply.

We cannot overemphasize the criticality and the supreme difficulty of interviewing true experts. First, it requires clarity about what you are and are not studying. Second, it requires clear articulation of the criteria used to identify experts. Even with clear articulation of the scope and the criteria used to identify experts, how do we communicate this to the instructors who will decide which student to send to us? How can we verify that the instructor understood and complied with the description of the selection criteria? We identified that we were unskilled at recognizing expert navigators, and we attempted to remedy this by conducting a focus group interview with expert instructors at the U.S. Army Ranger School. From this focus group, we acquired a set of criteria that reasonably describe expert navigators. Also, we refined our approach to target study of navigators, not patrol leaders.

As it turned out, the Special Forces instructors did a superior job of sending us expert navigators. We attribute their success to the following factors. First, the structure of the course requirements had previously weeded out beginners and advanced beginners over the past number of weeks. Second, the instructors had been working with this specific group of fifteen students for the past few weeks, so he knew each student's strengths and weaknesses. Additionally, we noticed that as we learned more and interviewed more students, we actually developed a sense about each navigator's real ability. The processes and cues described by true experts have a definite pattern, as described in a later section.

2.1.4 Conduct

We were interested in gathering pertinent data across all phases of the patrol. Furthermore, we know that activities conducted during the planning phase have a strong influence on the later success or failure of the patrol. However, by asking them to draw a map, we unintentionally focused the interview on the travel phase exclusively, thereby limiting the discussion of key points such as planning events and actions on the objective.

It is necessary to review the interviews and create the necessary descriptions of them as soon as possible. Notes alone will be insufficient aids for this analysis; we needed sketches and other artifacts. We also learned to become aware that further questions will likely emerge from early analysis of the interviews. We yielded to the temptation to "add-on" to the original protocol a few questions to probe into these emergences. Such tinkering changes the nature of the interviews so that they are in essence two different creatures. By not following this advice, we possibly corrupted data from the last two experts we interviewed.

2.1.5 Setting

We were fortunate. Most of the interviews were conducted indoors. Those conducted outdoors enjoyed clear, dry and warm weather. We were not adequately prepared to collect data in unfavorable conditions, such as extreme cold or wet weather. The field interviews were quite different from those done indoors. Indoors, we had two butcher pads with easels and lighting. In the field, we lay in the dirt, shining a flashlight on the student's map while scribbling notes on a clipboard. This method was nice in that it focused and sped the interview; unfortunately, we did not get as much detail nor did we obtain patrol sketches.

3.0 The Representation of Expertise

We represent the results of the interviews in four ways. First, we will provide high-level general results. From these, we will shift to a specific listing of the cues on which expert navigators rely. Third, we will supplement the general model with specific excerpts to show how expert navigators assess situations and make decisions. Finally, we will present a Key Decision Requirements Table that integrates the three other representations.

3.1 General Results

Analysis of the interview data shows some commonality across experts, as each expert described the use of four key mental processes: they rely on high-fidelity mental maps; they blend multiple cues; they adjust and recalibrate tools dynamically; and they visualize spatial information.

3.1.1 Mental Map Fidelity
During mission planning, experts carefully study the paper map and create a detailed mental map. During navigation execution, experts rely on the mental map over the paper map and stop to make paper-map checks rarely if ever. While we did not probe to specifically learn the mental map creation process nor its format or contents, the experts did refer to the information that they queried from their mental maps. These information characteristics include key terrain features, route specifications, navigation tools, and other spatial information. Clearly, the memorization of the route is the most important element. In most cases, the route included a general compass azimuth and measured distance. The routes were usually described as corridors rather than lines, and so each route had lateral boundaries. Checkpoints connect consecutive legs of the route and are usually described in relation to other landmarks. Key terrain features were included, with special reference to roads and bodies of water; man-made features were included but generally not as checkpoints or primary landmarks. The generation of the mental map is a complicated task, and the quality of the map is a clear indication of performance level, during both during planning and execution. Usually, during mission planning the navigator constructs a terrain model to use during mission rehearsal. There is a relationship between the quality of this terrain model and that of the mental map; probably the creation of the terrain model helps to reinforce the elements of the mental map. Although route information is an integral part of the mental map, experts report much greater detail. The quality of the mental map enables experts to make dynamic changes to their navigation tools, mentally simulate the consequences of decisions and generate stories to explain expectancy violations.

3.1.2 Blending of Cues

While walking, experts blend information from the environment and compare this processed information to their mental maps. The specific cues that are used will be discussed later. For now, we distinguish between major and minor cues. The major cues used are terrain features, pacecount and compass azimuth. The minor cues are the tactical and mission considerations. The relative weight applied to each cue depends primarily on environmental conditions, and we suspect that further research may reveal heavy individual differences influence. Weather, light and vegetation conditions all contribute to the visibility and traversability of the terrain features. Different environments provide more relative relief of terrain feature topography, and in some environments, man-made features may be more reliable and present; each factor affects the value of each cue.

3.1.3 Dynamic Adjustment

Experts use physical and mental navigation tools. Physically, they carry a paper map, check their headings using a magnetic compass and keep count of the steps they walk. Mentally, they use the pacecount information to estimate distance traveled and they rely on their mental maps. Through practice, navigators develop their pacecount, knowing how many steps equals a specific distance. Many factors converge on the known pacecount, such fatigue, different terrain types, and visibility. As the navigator moves, he acquires new information that he uses to update his mental map. Finally, while walking over and around terrain, the actual direction of travel will deviate drastically from the intended compass azimuth heading. All of these factors require navigators to constantly monitor their tools and make adjustments to them. Experts can make these adjustments without stopping, dynamically as the conditions change. As a result of reliance on this process, experts trust their mental maps and rarely if ever stop to consult the paper maps; they tend to indirectly trust the paper map, since it is the source of their mental map. The decision to halt the patrol and make a map check is a last resort; map checks lower morale and patrol confidence in their navigator. Minimal map checking is the organizational expectation.

3.1.4 Spatial Visualization

From map study alone, experts are able to generate visualizations of what the terrain should look like. Conversely, while walking, experts can visualize how the present terrain would look if depicted by a two-dimensional, paper map. These two related skills are hallmarks of good navigators. We will term the first process “map to ground” and the second “ground to map.” The map to ground process is primarily important during mission planning, and it enables the navigator to select the route, create a mental map and build a terrain model. The ground to map process is most useful during enroute navigation. Experts rely on it whenever they compare their mental map to the real environment, which happens continually when confirming their route and arriving at potential checkpoints.

3.2 Cue Inventory

Adapted from Hoffman, et al., (1998) we provide a cue inventory in Table 1, with cues grouped by category. The description of each cue listed in Table 1 follows.

Category of Cue	Cue
Navigation Tools	Compass Azimuth
	Pacecount
	Paper Map
	Mental Map
Environmental Conditions	Ground Slope
	Vegetation
Mission Conditions	Time
	Input from Other Patrol Members
Terrain Features	Road
	Body of Water
	Topography
	Man-made Feature

Table 1: Cue Inventory grouped by Category.

3.2.1 Navigation Tools

Compass Azimuth
The navigator always carries a compass that is used to determine the direction of travel and direction to landmarks. Depending upon the task organization of the patrol, other members may be responsible for ensuring that the patrol travels on the intended azimuth. Expert navigators have a high tolerance for deviations from the intended azimuth since they combine the compass azimuth with other cues to maintain orientation.

Pacecount
The navigator counts his steps and accumulates them while walking. As with azimuth, other patrol members may be tasked to keep a pacecount for the navigator. Over practice, the navigator knows how many paces he must walk to cover one hundred meters. Since the stride length and rate vary based upon terrain, vegetation, slope, fatigue, speed of travel, visibility and weather, the pacecount can be a misleading, inaccurate cue. Expert navigators are able to recalculate their pacecount dynamically as conditions change, giving them a more accurate, reliable measure.

Paper Map
The map is the primary source of information used during route planning, and it provides direct vegetation and elevation data. The navigator usually carries a map in his pocket while walking. Experts report that while walking, they make map checks extremely rarely, only as a last resort.

Mental Map
During route planning, the navigator studies the paper map and generates a corresponding mental map. The specific symbols, format and contents of the mental map are unclear. While walking, most navigators compare their physical surroundings to their mental map, so it is the main source of information once the patrol begins movement. Experts are able to rapidly generate detailed mental maps, hence relieving their dependence on the paper map.

3.2.2 Environmental Conditions

Ground Slope
Through map study, experts are able to visualize the terrain as if they were walking over it. One component of this visualization is the slope of the ground. Not only is the slope of the surrounding terrain important, but also the slope of the ground immediately underneath the navigator’s boots. While walking, experts are highly sensitive to changes in the ground slope, and they use both visual and kinesthetic cues to monitor the state.

Vegetation

The paper map usually depicts vegetation as green areas, but the map does not characterize the type of vegetation. From map study, the navigator will generate expectancies of how the vegetation will vary across the proposed route. These expectancies are critical as the type of vegetation has strong influence on cover, concealment and movement effort. Experts are able to make fine discriminations in vegetation quality.

3.2.3 Mission Conditions

Time

During route planning, the navigator carefully considers the time constraints dictated by the mission. The navigator must select and then execute a route that will result in the patrol's arrival at the objective at the prescribed time. An ability to estimate travel times from map study enables accurate planning. Route descriptions included spatial and temporal components. While walking, the navigator's expectancies about the order of landmarks and terrain features all are time-stamped. While distance traveled, environmental conditions and fatigue level can give clues about the time, a watch is the primary source.

Input from Patrol Members

While the navigator is primarily responsible for route planning and execution, other patrol members are also involved. The patrol leader is the main source of mission-related information. At any time, he can command that the navigator increase or decrease the pace of movement or that the route be changed. In addition, the leader can assign navigation-related duties, such as keeping the pacecount or azimuth, to other patrol members.

3.2.4 Terrain Features

Roads and False Roads

Navigators commonly use roads as landmarks and checkpoints, and maps usually depict roads. Depending upon the environment, the roads may be paved, gravel or dirt. For security reasons, navigators strongly avoid improved or paved roads. Patrols cross roads; they never travel on a road as civilians typically would. Experts are able to make fine discriminations between types of roads, such as paved, improved, main or secondary. One reason why roads can be tricky landmarks is that often a patrol will encounter a road that does not appear on the map. These are commonly referred to as "false roads" because the road they see is not the planned landmark. Experts are able to process cues such as the road's bends, taper, slope and evidence of traffic to correctly identify false roads.

Bodies of Water and False Bodies of Water

Water features such as river, creeks and streams are commonly used landmarks. At times larger bodies of water, such as ponds and lakes are used. The level of water is an important cue that skilled navigators report using. The extreme case of a dry creek is common during the dry seasons. As with roads, navigators contend with the possible presence of false water bodies. Recent rainfall can channel water through low ground that is not depicted as a water body on the map; conversely, dry environmental conditions can leave the low area depicted on the map as water, completely dry. Experts are able to make use of a combination of cues to determine which dry creeks are false and which are true.

Topography and False Topography

The terrain's relief and elevation are the most commonly used navigational features. As the scale of the map increases, there is less detail depicted by the map, so only the most prominent hills can be pinpointed by map study. The navigational skill of reading a two-dimensional map and visualizing a three-dimensional space hinges on the ability to interpret map relief and elevation symbology. Experts can do it. Again, navigators must contend with possible false hills, valleys, draws and ridges. While walking, experts are able to pick out the true features and discount the false ones.

Man-made Objects
With the exception of roads, skilled navigators choose to attend to natural terrain features rather than man-made objects, such as buildings. This tendency seems to be sourced in the reality that combat operations and non-combat inhabitation can drastically affect the presence and appearance of man-made structures.

3.3 Situation Assessment Records

As described by Hoffman, et al., a situation assessment record highlights the points where the expert made a decision based upon a revised assessment of the situation (1998). After examining the example presented there and comparing it to the elements of the Recognition-Primed Decision Model (R.P.D.) as diagrammed by Klein (1998), we saw an opportunity to use the R.P.D. pattern to describe expert navigation and describe the situation assessment record. There are three different variations of the flow through the R.P.D. model, and each variation is related to the decision-maker's recognition of the situation. Variation 1 describes episodes where the expert recognizes a typical situation. The fact that the situation is typical means the expert takes action immediately, without thinking; the recognition of the situation primes the appropriate action. Variation 1 typifies the quick and accurate behavior frequently associated with expertise (Dreyfus, 1997).

Sometimes, even experts are faced with situations that are not immediately recognized as being typical. Here begins Variation 2. During these episodes, the expert directs mental effort to the process of recognizing the specific cues and patterns that comprise a situation. As the R.P.D. model asserts, this diagnosis involves two mental processes. First, the expert identifies the features of the situation; then she compares the present features to other situations to match the feature contents and arrive at situation recognition. Second, the expert creates a story to explain how the features might fit together and what actions might have caused the situation to arise. Often, the decision-maker will alternate between the feature matching and story creation processes, until the current situation can be categorized as being typical. Once the situation is recognized, then the expert takes action as in Variation 1.

Variation 3 begins with the recognition of a situation. However, unlike Variations 1 and 2, in these cases, the expert does not immediately know what to do. Mental effort is expended not on situation recognition but response evaluation. In some ways, the expert behaves as a competent performer would (Dreyfus, 1997). She must figure out what to do. The R.P.D. model specifies that this action evaluation happens in a way that differs from traditional decision-making theory. Rather than simultaneously comparing multiple responses, the expert considers them singularly. The decision-maker mentally simulates forward from the current situation to the simulated outcome of the first action that comes to mind. If the outcome is workable, then the expert implements it. If not, then she discards it and considers another option. Sometimes, this simulation will identify an outcome that satisfies most of the relevant goals but not all of them. In these cases, the expert may make slight changes to the action and then rerun the simulation.

Obviously, the expert's recognition of the situation is the key. This recognition generates four "by-products" (Klein, 1998) or types of mental constructs useful to the expert's future performance: expectancies, relevant cues, plausible goals and typical actions. For a given situation, there are associated expectancies about what will happen next. Sometimes, these expectancies are expressed in terms are relevant cues. The expert attends to the relevant cues to confirm or disconfirm the expectancies of the situation. The violation of an expectancy often triggers a new situation assessment. Also, the situation defines which goals are plausible. Decision-maker attention to relevant cues and input from the organization can cause the relative importance of these goals to shift, and sometimes these shifts will generate a new situational assessment. Finally, to achieve the goals, the expert has a set of typical actions associated with each situation. In Variations 1 and 2, the expert implements one action from this set without evaluating each possibility (Klein, 1998).

We represent our characterization of expert land navigation performance using this model. Specific items for each of the four by-products are illustrated in Table 2. Next, we present one story, drawn from our interview data, to illustrate each of the three Variations.

The Standard By-Products of the Expert Navigator's Situation Assessment	
Expectancies Generated by evaluation of the situation with regard to the mental map.	Relevant Cues Selected from the cue inventory categories: · Navigation Tools · Environmental Conditions · Mission Conditions · Terrain Features
Plausible Goals Selected from the list of standard goals: · Maximize Speed · Maximize Stealth · Minimize Exertion · Maintain Orientation	Typical Actions The Standard Typical Action is one of Three Methods: · *Arrive at Checkpoint* Method 1. Confirm checkpoint if needed. 2. Reset pacecount. 3. Change azimuth if needed. · *Confirm Route* Method 1. Maintain pacecount. 2. Maintain azimuth. · *Error Recovery* Method 1. Confirm checkpoint if needed. 2. Reset tools if needed. 3. Map Check if needed.

Table 2: The specific by-products of land navigation situation assessment (Adapted from Klein, 1998).

Example of Variation 1 – "I know the situation, therefore I know the course of action."
"Continue Mission"

Situation One: On course between start point and checkpoint 1
Relevant Cues: Standard.
Plausible Goals: Standard.
Typical Actions: Standard.
Expectations: Expect to begin by moving uphill, then we will cross a road.
Course of Action: *Arrive at Checkpoint* Method.

Situation Two: On course between checkpoint 1 and checkpoint 2
Relevant Cues: Standard.
Plausible Goals: Standard.
Typical Actions: Standard.
Expectations: After crossing the road, we will hit a draw. We will box around the draw. Then we should cross a road.
Course of Action: *Arrive at Checkpoint* Method.

Table 3: Situation Assessment Record for R.P.D. Variation 1.

3.3.1 Situation Assessment Record of Variation 1

All of our participants operated under Variation 1 conditions most of the time. They recognized the navigation situation as being typical, and they just continued to navigate – walking and scanning the environment. The record is show in Table 3. The relevant cues, plausible goals and typical actions are all drawn from the standard sets, as listed in Table 2. The story begins as the patrol moves from its starting point through checkpoint one and onto checkpoint two. The navigator initially expects to walk uphill, and then cross a road. As these expectations are met, the navigator is acting according to the "confirm route" and "arrive at checkpoint" methods. After crossing the road, he navigates to checkpoint number two, consulting his mental map to update his expectancies for the respective leg of the route.

3.3.2 Situation Assessment Record of Variation 2

As shown in Table 4, our example of Variation 2 comes from a participant who was able to recognize his own error and correct it dynamically, on the move without disrupting the flow of the patrol's movement; it is likely that the other patrol members were not even aware that the error occurred. The patrol was moving smoothly from checkpoint to checkpoint. Enroute to the patrol's sixth checkpoint, the navigator expected to cross two draws and then an improved road. However, an anomaly violated this expectation, as he crossed a secondary road after moving only 100 meters past the fifth checkpoint. After matching the relevant features of the situation, he considered a story in which they had crossed the improved road too far north. This was caused by mistakenly cutting the last leg short before changing heading. The source of the error was that his pacecount had become mis-calibrated, likely due to fatigue. He verified this story against his mental map and the visible terrain features, and assessed the situation to be error recovery. Relying on his detailed mental map, he knew where the patrol was but his pacecount was off. Remembering from his mental map, the distance between the improved and secondary roads, he re-calibrated his pacecount and later confirmed his revision.

3.3.3 Situation Assessment Record of Variation 3

Our example of Variation 3 begins with an anomaly, and is presented in Table 5. Enroute from checkpoint four to checkpoint five, they walked 400 meters and the navigator expected to arrive at checkpoint five. They did not. From feature matching and story generation, the navigator accurately reassessed the situation and realized that they had not reached the planned checkpoint four. However, the solution was not immediately obvious, since checkpoint five was in enemy territory. The patrol leader had established a temporary defensive position at checkpoint four and currently, most of the patrol members were located there, preparing to engage the enemy. Although the navigator recognized the situation, and he knew where they were, the situation was not typical and he immediately evaluated possible actions. He first considered going back to checkpoint 4 and relocating it, but then he discounted it since it would cause too much confusion and lower morale, which could jeopardize the patrol. Relying on his detailed mental map, he mentally constructed a new route from the present checkpoint four to the desired checkpoint five and realized that would be the simplest action. But, what if he got shot? The rest of the patrol would not know where they were. So, he decided to change the route and inform the patrol leader of the change; the leader would then decide how to disseminate the route change.

Example of Variation 2 – "What is the situation?"
"I'll just do a quick dynamic pacecount recalculation…"

Situation One: On course between checkpoint 2 and checkpoint 3
Relevant Cues: Standard.
Plausible Goals: Standard.
Typical Actions: Standard.
Expectations: We will cross another road. The Pacecount here should be 300m. We will next be able to see a hill. Next, we should cross a major road.
Course of Action: *Arrive at Checkpoint* Method.

Situation Two: On course between checkpoint 3 and checkpoint 4
Relevant Cues: Standard.
Plausible Goals: Standard.
Typical Actions: Standard.
Expectations: We will identify a bend in the road at 450m.
Course of Action: *Arrive at Checkpoint* Method.

Situation Three: On course between checkpoint 4 and checkpoint 5
Relevant Cues: Standard.
Plausible Goals: Standard.
Typical Actions: Standard.
Expectations: We will cross a major road at 1000m.
Course of Action: *Arrive at Checkpoint* Method.

Situation Four: On course between checkpoint 5 and checkpoint 6
Relevant Cues: Standard.
Plausible Goals: Standard.
Typical Actions: Standard.
Expectations: We will cross two draws. Then we will cross an improved road.

Anomaly: We crossed a secondary road at 100m.
Diagnose:
Feature Matching: Traveling on the right compass heading. Pacecount is 100m. Crossed road. Have not crossed draws. (Matches these features to the features of his mental map.)
Story: On our last leg, we must have stopped too far north. Then on this leg, we crossed the major road too far to the north/east.

Situation Five: Off course between checkpoint 5 and checkpoint 6
Goal: Reorient and compensate for error.
Course of Action: *Error Recovery* Method: Recalculate pacecount, mentally change the route.

Situation Six: On course between checkpoint 5 and checkpoint 6
Relevant Cues: Standard.
Plausible Goals: Standard.
Typical Actions: Standard.
Expectations: We will cross two draws. Then we will cross an improved road.
Course of Action: *Confirm Route* Method

Table 4: Situation Assessment Record for R.P.D. Variation 2.

Example of Variation 3 – "I know the situation…what do I do about it?"
"Hey, we're too far from the checkpoint…"

Situation One: On course between checkpoint 2 and checkpoint 3
Relevant Cues: Standard.
Plausible Goals: Standard.
Typical Actions: Standard.
Expectations: Should enter triangular open area between roads. Should then cross major road.
Course of Action: *Confirm Route* Method.

Situation Two: On course between checkpoint 4 and checkpoint 5
Relevant Cues: Standard.
Plausible Goals: Standard.
Typical Actions: Standard.
Expectations: Checkpoint 5 should be 400m away on set azimuth.

Anomaly: At 400m, did not hit checkpoint 5.
Diagnose:
Feature Matching: Two hills, one to our left and one to our right. Our compass heading is correct. Pacecount is 400m. Estimate that checkpoint 5 is still 300m away distant.
Story: We must have misplaced checkpoint 4. On our last leg, we did not go far enough east. That means we are 400m west of our planned location.

Situation Three: Erroneous checkpoint 4
Goal: Maximize Stealth. Minimize patrol confusion.
Typical Actions: None.

Evaluate Actions: Go back and move patrol's defensive position (Mental Simulation).
Will it work: No… patrol is preparing to engage the enemy.
Evaluate Actions: Change route from checkpoint 4 to checkpoint 5 (Mental Simulation).
Will it work: Yes, but…Patrol Leader must be informed.
Evaluate Actions: Change route and inform Patrol Leader. (Mental Simulation).
Will it work: Yes.
Course of Action: Change route and inform Patrol Leader.

Situation Four: On course between checkpoint 4 and checkpoint 5
Relevant Cues: Standard.
Plausible Goals: Standard.
Typical Actions: Standard.
Expectations: Checkpoint 5 should be 700m away on new azimuth.
Course of Action: *Confirm Route* Method

Table 5: Situation Assessment Record for R.P.D. Variation 3.

3.4 Key Decision Requirements

A listing of the key decision requirements is useful to determine which decisions are particularly critical, and which skills enable the decisions (Hoffman, et al., 1998). Such mapping helps direct training resources. Table 6 presents a portion of the key decision requirements for land navigation. There we list five key decisions. For each of them, we propose an explanation for why the decision is difficult and how experts make it. The final column traces the process back to the four key mental processes that we introduced earlier.

What Is The Decision?	Why Is It Difficult?	How is it made?	What enables decision?
Selecting the Route	Maps do not provide enough information; difficult to estimate environmental conditions	Mental Simulation	High-fidelity mental map; spatial visualization
Memorizing the Route	Limited Time; must decide which features to memorize	Mental Simulation	High-fidelity mental map; spatial visualization
Identifying Terrain Feature	Environmental conditions can limit visibility	Compare environmental cues to expectancies	High-fidelity mental map; cue blending; spatial visualization
Discounting False Terrain Feature	Maps do not show all possible terrain features; must rely on multiple cues; requires multi-tasking attention	Compare environmental cues to expectancies; Mental Simulation	High-fidelity mental map; cue blending; recalibrate tools; spatial visualization
Recognizing misorientation	Difficult to recalibrate tools enroute; difficult to identify terrain features	Compare environmental cues to expectancies; Mental Simulation	High-fidelity mental map; cue blending; recalibrate tools; spatial visualization

Table 6: Key Decision Requirements (Adapted from Hoffman, et al., 1998).

4.0 Future work

The results of our elicitation and representation efforts lead us to reconsider three elements of future work. First, we discuss the methods we plan to use for future knowledge elicitation. Next, we discuss our view of the relevance of pursuing an expertise representation that is executable. Finally, given sufficient forms of representation, we consider how to best use this knowledge to improve current training practices.

4.1 Methods

The C.D.M. was an appropriate method for us, but in our future work, we want to probe more deeply. So we are considering combining the C.D.M. with direct observation methods, reminiscent of previous work done by Klein Associates in the study of tank platoon leaders (Brezovic, et al., 1990). At an early stage of the project, we rejected direct observation primarily because we deemed it to be too intrusive and felt that we would not capture the underlying cognitive processes that control overt behavior. Also, we felt that interviewing would be more efficient in that we could mentally direct the expert to decisions that were critical, rather than potentially spending hours in the field observing an expert perform relatively uncritical tasks that never fully demanded his expertise.

This kind of work might benefit from a longer-term perspective, based upon an established relationship between the research team and the community. We see that in the long run, the most efficient method may involve a more ethnographic approach. We define such an approach primarily in terms of the amount of time and effort the elicitors spend in the community, and the attitude that motivates them. If we enter the community with rigid expectations, fixed understanding of the culture and a predetermined need and vision for improving training, we are likely to meet justified resistance at one level or another and derive less than valuable results. Rather, we endeavor to enter the community as an ethnographer would, with open eyes, blank canvas and absent expectations. We may learn that indeed the traditional, mysterious development of expertise is the appropriate one for the members of this culture. Then again, over time, they may see the value of studying and demystifying the skill. Probably, together we will find a common ground between these extremes.

Such an approach requires commitment to the project and a patient tolerance of short-term resistance and fuzzy, qualitative interim results. Obviously, such an approach also requires time and a pure desire to hear to the culture. The typical two-day trip to visit the community appears to be efficient: we arrive on Tuesday, coordinate with the school that evening, conduct the interviews on Wednesday and hold a wrap-up meeting on Thursday. But in the long run, it doesn't drive deeply enough. Rather, supply the elicitation team with food and water, arm them with tools for C.D.M., direct observation and informal discussions and "parachute" them into the woods for a month; the woods is the natural setting for this task and that's where we must study it.

Our future elicitation efforts require carefully constructed observations and interviews, to ensure that we are clear about what and whom we study. For now, we have attempted to select expert navigators for study. Likely, it would be optimal to study navigators across all ability levels to better understand the transitions between and characteristics that distinguish the stages of skill development (Dreyfus, 1997). In fact, we may find that navigators at the level of competent or proficient may assess situations as accurately as experts but provide better articulation of the processes they use since they may be more conscious of the process than experts who assess more automatically. Similarly, during our first focus group interviews, we inadvertently collected data about patrol leaders, not navigators. Patrol leaders do navigate, but it is not their primary responsibility. We had mentally fused navigation expertise with patrol leader expertise, and later learned that the data we gathered during the focus group applied more to leader expertise than navigator expertise. The important theme is to strive to be able to articulate the purpose of the study and target the correct sample of the population for the elicitation efforts.

4.2 Executable Representations

An executable model of expertise was our initial goal, since it was an integral component of the envisioned training system. While we still value an executable representation, we have relaxed the urgency of forcing the representation to be executable. We attribute this change of perspective to our growing understanding of the task and the infantry community. We now see training products that do not require executable representations; these we discuss in the next section. Additionally, we are unsure if the composite, complex skill can be represented by the current software approaches.

Pew and Mavor provide a comprehensive report of the most popular and powerful cognitive architectures (1998). One critical limitation of these architectures is the simplified and abstracted situation awareness modules. It appears that these modules cannot adequately represent specific components of the R.P.D. model: these components are expectancies, story generation and mental simulation. Furthermore, if the virtual navigator were to behave like a human, it would have to make a number of perceptual judgements based upon its observation of the three-dimensional, virtual environment. Modeling of this perceptual process is limited due to both primitive visual perception models and the required abstraction involved with construction of a virtual environment database. On the other hand, those components of the R.P.D. that can be expressed in rule format can probably be adequately represented by these architectures: these components are goals, actions, and methods. However, the more the representation relies on rules for its operation, it is likely that the less expert-like is the cognitive process fidelity of the virtual navigator (Dreyfus, 1997). For applications in which cognitive fidelity must be high, standard executable representations may not afford the right approach yet.

4.3 Training Navigators

Finally, we have restrained our sprint for an executable virtual navigation trainer. Indeed, there are applications that extend from a realistic executable model. One component of the envisioned system was an apprentice master relationship between the student and virtual coach. We still value the apprenticeship model, but we now believe that students would benefit from applying that approach to traditional physical practice as well as virtual practice. Other possible products that extend from non-executable representations include case studies and structured storytelling.

Short of the full-blown virtual apprenticeship, we are encouraged by two possible interventions. Both are computer-mediated, and one requires a virtual expert while the other does not. As discussed earlier, one core skill is the ability to make route and spatial judgements based upon their map to ground and ground to map visualization abilities. A system that focuses on the route planning phase, hence training map to ground visualization, could be driven by an executable representation that makes decisions based upon the perception of two-dimensional map features. To train ground to map visualization, we envision a system that does not require an executable representation. The route execution system would provide virtual practice for the student as he virtually travels from checkpoint to checkpoint along a prescribed route. The computer could provide direct feedback by displaying geocentric map perspective views and egocentric navigator perspectives under the student's control. We have already successfully prototyped a similar system for helicopter pilots (McLean, 1999).

As it should, this discussion circles back to the practical limitations on military training resources. If we had plenty of experts, who were superb instructors, and we provided them with the requisite time for training the apprentice, we probably would have no need to consider other alternatives. But the reality of the situation is that there are few experts and, of them, even fewer are also expert instructors. The units who do have these experts certainly are unable to maximize the contact time between them and the students. Cast under the light of these practical constraints, virtual apprenticeships make more sense. The path to that place requires intensive and efficient study of expert navigators, coupled with the appropriate representational forms. Perhaps a by-product of our studies will be our own successful navigation toward that objective.

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