Enhancing Decision-Making by Explicitly Training Battlefield Visualization Skills

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ABSTRACT

As the vision of network-centric warfare (NCW) becomes a reality in the Future Force, it is clear that trading steel for information represents a true revolution in military affairs. This places increasing demands on individual soldiers and commanders to incorporate this additional information into the military decision-making process (MDMP). To be truly useful for decision-making, new information must be integrated into the warfighter's mental image of the current situation and future events, and be accurately related to the mission. This process, called battlefield visualization, is often more of an art than a science and is not accorded the same level of training rigor as other aspects of military decision-making.

In this paper, we will present an approach for improving the quality of military decision-making instruction by explicitly training the basic visualization skills underlying battlefield visualization. This approach is based on a careful analysis of the information and cognitive skill requirements for a company-level cordon and search in a Military Operations in Urban Terrain (MOUT) environment. In addition, the approach includes deliberate pedagogical strategies to engage trainees in active, guided practice and to prompt them to self-explain their actions. The goal is to produce visualization training (consisting of curricular materials and a digital visualization training tool) that transfers to the battlefield regardless of whether the soldier is using a new command and control system or grease pencils on an acetate sheet. While this work is ongoing, our current framework suggests that this approach will demonstrate the effectiveness and utility of human-computer visualization for military decision-making training and represent a significant step forward in digital instruction technique and product.

ABOUT THE AUTHORS

Jack D. Zaientz is a Research Scientist with Soar Technology, Inc. His current research focuses on intelligent interface design, information visualization, and human interaction with complex knowledge-rich environments, including C4ISR and military simulation. Mr. Zaientz also is interested in human internal, external and shared knowledge representations. He received a Masters of Human Computer Interaction from Carnegie Mellon's Human-Computer Interaction Institute (2001). For his masters project he worked in an interdisciplinary team designing tools for visualizing the behavior of generative cognitive behavior models for the NASA Ames Research Center.

Lisa Scott Holt is a Research Scientist with Soar Technology, Inc. During a 9-year tenure in the Center for Innovation in Learning at Carnegie Mellon University, she received her Ph.D. in Cognitive Studies in Education from the University of Pittsburgh in 2001. For her dissertation she designed, implemented and evaluated an interactive tutoring environment for introductory physics. Dr. Holt's current research focus is in the design of technology tools to support learning and the design of interfaces based on an information-processing model of human cognition. She is also interested in assessment methods to reveal what learners actually know and are able to do with their knowledge.

Scott D. Wood, is a Senior Scientist with Soar Technology in the area of human-machine interaction. Dr. Wood has over fifteen years of research and industry experience in the areas of software development, e-business consulting, cognitive modeling, and human-computer interaction. His doctoral research included extending GOMS (Goals, Operators, Methods, Selection Rules) modeling to allow for human error, developing techniques for predicting where human errors would occur in an interface, and testing those techniques by applying them to web applications.

In addition, he spent four years in the U.S. Army attached to 5th Special Forces Group and other special operations units. He earned a B.S. in Computer Science (1990) from Tulane University, and M.S. (1994) and Ph.D. (2000)

Christopher G. Healey is an associate professor in the Department of Computer Science at North Carolina State University. Healey received a National Science Foundation CAREER award for research in perception and visualization in 2001. He received his Ph.D. in Computer Science at the University of British Columbia in Vancouver, Canada, with a specialization in computer graphics. He was a recipient of National Science and Engineering Council of Canada (NSERC) postdoctoral fellowship for doctoral degree research. Healey completed his postdoctoral studies at the University of California at Berkeley. Healey's current research interests include scientific and information visualization, computer graphics, human perception, artificial intelligence techniques for mixed-initiative interaction, data compression, navigation in virtual worlds, and the role of aesthetics in information representation.

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Laura Strater is a Senior Research Associate with SA Technologies. Ms. Strater's recent projects include conducting a Goal-Directed Task Analysis to identify the SA requirements for Infantry Platoon Leaders, developing and applying Situation Awareness measures for the Infantry environment, particularly at the Platoon Leader level, as well as designing and developing training programs for Infantry Platoon Leaders aimed at improving SA. She has been employed at SA Technologies for over four years. She has over 7 years experience in conducting human factors research projects, including test design and development, computer programming, data collection and analysis, and report writing.

John R. Hyatt is a military subject matter analyst for SA Technologies. In this position he is developing Goal Directed Task Analyses for roles in the FCS Unit of Action. His work with SA Technologies over the past 5 years has included developing Situation Awareness decision-making tools for infantry platoon and squad projects with the Army Research Institute and developing SA schema trainers for infantry platoon leaders. With 15 years of active service as a Regular Army Infantry Officer, he has experience working in both the small unit infantry environment as well as on the headquarter staffs supporting small unit infantry.

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THE PROBLEM

Increasing Information-Processing Demands

One of the main goals of network-centric warfare (NCW) is to eliminate traditional information stovepipes to speed the flow of information to the end user and to rapidly increase the rate at which information is transformed to be militarily significant and decision centered. Irrespective of the concepts and goals of NCW, sound, rapid, and accurate decision-making remains at the heart of all aspects of battle command. To be truly useful for decision-making, new information must be integrated into the warfighter's mental image of the current situation and accurately related to the mission. Having a solid understanding of the situation is necessary to ask the right questions; having the right information is necessary to answering the questions correctly and understanding the consequences of the answers.

Developing accurate and sufficient mental models for battlefield situations and decision-making is a necessary prerequisite for understanding the situation and acting on key information. Visualizing situations, information, and processes is a useful technique for developing such mental models, understanding how new information relates to decisions, and understanding what information is necessary to make good decisions. This involves at least three different levels of warfighter knowledge that must be learned to achieve and capitalize on information and technological superiority: 1) knowledge of basic visualization techniques for military decision-making, 2) knowledge of basic visualization tool techniques, and 3) knowledge of how to apply visualization techniques with tools in militarily relevant situations. We propose to improve the quality of military decision-making instruction regarding visualization of information by, 1) further developing the scientific basis for developing mental models, visualizing information and situations, and teaching visualization techniques, 2) by developing courseware to present the concepts in 1, and 3) by developing computer-based instruction software to facilitate the teaching process and reduce training costs. If successful, this effort will demonstrate the effectiveness and utility of human-computer visualization for military decision-making and represent a significant step forward in digital instruction technique and product.

Training Needs

Battlefield visualization is defined as "the mental process which supports the commander's decision-making process" (Department of the Army, 1995). It "lies at the center of battle command" and is "an essential leadership attribute of the commander" that is "critical for accomplishing missions." Battlefield visualization is a three-step process whereby the commander develops a clear understanding of the current situation, envisions a desired end state, and visualizes the sequences of activity that will move his force from its current situation to the desired end state (Department of the Army, 2002). If training solutions are going to improve tactical-decision making, they must address battlefield visualization. Future commanders must be provided with training that enhances their ability to obtain, configure, present, and assimilate information. Training must map the computer-based model for why and how information is presented with the human mental model for why the information is needed and how best it can be understood. Understanding this mapping and developing training methods, and materials, and tools that exploit it, is the primary challenge that we address in this project.

While many important skills, such as the Military Decision Making Process (MDMP), have become well-defined processes, battlefield visualization in support of good decision-making is still considered an art. A central goal of this work has been to examine how a combination of novel computer visualization techniques, task analysis, intelligent tutoring, and other digital learning techniques could be used to transform battlefield visualization from an art to a science. This section presents a discussion of how such skills are currently taught in formal military courses (i.e., "schoolhouse" training), an assessment of battlefield needs, and an analysis of fundamental gaps between skills that are taught versus required skills. The context for this work is company-level commanders in MOUT environments (Military Operations in Urban Terrain) with an emphasis on Cordon-and-Search missions.

Leadership and battlefield skills for company-level MOUT operations are taught in the Infantry Captains Career Course at Ft. Benning, via correspondence course (US Army Infantry School), and through similar courses. While there is no specific lesson in battlefield visualization or the use of visualization techniques, aspects of it are taught throughout the coursework in the context of other lessons.

The somewhat disjointed organization of command doctrine is also reflected in current field manuals (e.g., FM 90-10). To help bridge the gap between formal training and operational need, training circulars such as TC 7-98-1 Stability and Support Operations Training Support Package (Department of the Army, 1998) combine various doctrinal elements to address specific requirements for practical missions such as cordon and search. However, even these more practical training support materials do not address visualization skills in a way that can more fully prepare new officers for battle conditions. TRADOC PAM 525-70 (Department of the Army, 1995) discusses the art, science, and integration of battlefield visualization skills in a general way. It notes that computer and digital technology are essential, but it does not discuss how warfighters can or should make use of specific technologies to support visualization and situation awareness. It also does not discuss how such essential skills are best connected with the MDMP.

APPROACH

Context: Cordon & search in MOUT environment

MOUT operations represent one of the most challenging and dangerous of all classes of military missions because terrain, infrastructure, cultural issues, and other aspects of the domain negate many of the technological advantages held by the U.S. military. Information, understanding and use of that understanding to make better and faster tactical decisions is among the most important weapons for achieving success in the urban environment. A frequent mission type where company commanders face numerous decisions is cordon and search. In this type of operation, commanders are typically searching for specific items (e.g. weapons) or people (e.g. fugitives). The main tasks for a cordon and search are moving to the objective, establishing the cordon to isolate and secure the objective, and conducting the search. While a cordon and search is conceptually straightforward, there are several key decisions that must be constantly evaluated and many factors that a commander must consider. Some key decisions are:

- What is our task and purpose (mission)? How do we know when our mission has been accomplished?
- Has the tactical situation changed? If so, has it changed the mission?
- Is there an unexpected threat? If so, what is its nature?
- Can I still complete the mission with available resources? If not, are additional resources available?
- Is there a secure evacuation route if necessary?

Each of these decisions relies on an accurate assessment of available information, an understanding of how that information impacts the current situation, and the commander's ability to use that understanding to accurately predict future situations that result in a successful mission. In evaluating these decisions, commanders are trained to consider several key factors, each of which evokes its own set of questions. Factors for cordon and search might be:

- **Mission** – What type of search is required, what is to be sought, and what is the desired end-state? Is the mission conducted under surgical, precision, or high-intensity conditions?
- **Enemy** – What type of resistance is to be expected? How well are they armed and organized? Are they likely to be reinforced?
- **Terrain & Weather –** What is the geographic layout? What are best routes in & out? What are the best covered and concealed locations for friendly or enemy troops?
- **Troops Available –** Do I have enough troops to accomplish the mission? Do they have the right weapons, equipment and training? Do they have enough ammo and supplies?
- **Time Available –** Do we have time to be careful and methodical, or is speed critical?
- **Civil Considerations** – Is the local population hostile, friendly, or neutral? Has there been a history of unrest in the area? What other cultural considerations must be considered? How do the Rules of Engagement impact the mission?

These key factors are, of course, interrelated such that changes in one factor can affect other factors. For example, any change to the mission will cause almost all other factors to be reevaluated. Although commanders are responsible for evaluating the key decisions and factors constantly, it is not possible for them to deliberately consider each question constantly. Instead commanders and other expert decision-makers focus on changes to the situation to prompt deliberate evaluations; this reduces and simplifies the commander's decision to just one: has my situation changed? Instead of evaluating each new piece of information according to a vast set of criteria, the one question that can quickly filter irrelevant information is whether the new information changes the current situation. If it does, then the deeper issues can be further explored.

Focus: Cognitive visualization skills

External Visual Representations

There is a long tradition of humans designing visual representations to support higher-level communication and reasoning. These representations use a range of visual depiction styles, showing concrete visible things, and graphical grammars, representing invisible abstract concepts. (Tversky, 2001) Early examples include drawings, paintings, maps, and petroglyphs. More contemporary examples include photographs, television and movie images, geographic information system (GIS), radar and meteorological displays, as well as 1st and 3rd person computer game screens. Since depictions are based on concrete objects or locations in either the real or a simulated world they tend to have strong spatial alignment with that world and can be considered a structured viewport into that world. This viewport does not have to provide an exact photo-realistic view, however. Research and commercial systems have explored many ways to add additional information to a depiction by manipulating image features including color or luminosity coding screen regions, smoothing road networks, or adding or removing specific terrain feature layers.

Historically, graphics evolved out of depictions to communicate concepts that were difficult or impossible to directly depict, such as proper names, abstract entities, causality, quantifications, and negations (Tversky, 2001). Contemporary graphic forms include logic diagrams such as those devised by Euler and Venn (Shin, 2002) and information graphics such as bar charts, box plots, time lines, flow and organizational charts and network diagrams (Harris, 1999) While graphics provide the advantage of being able to express these abstract concepts, they have lost the transparency of realistic depictions. In addition, while information graphics usually have a strong internal spatial orientation, such as vertical and horizontal axis, this orientation is only metaphoric or analogous to any external world. The implication of this loss of representational transparency and the lack of external spatial referents is that, while graphics provide a range of benefits, any use of graphics generally requires training.

When appropriate, combining visual depictions and graphics can increase the expressive power of the representation by leveraging the strong spatial alignment and ease of interpretation of the depiction with the abstract expressive power of the graphic. This approach is often taken in Intelligence Preparation of the Battlefield, where maps and satellite imagery are annotated with geometric areas of interest, and military Course of Action sketches where abstract time-based operational graphics are annotated on local terrain maps.

Cognitive Benefits of Representations

Researchers in cognitive psychology, mathematics, and a range of other disciplines have identified a number of basic principles that underlie the construction of external visual representations that support improved human reasoning or task performance. These principles generally focus on two main points. The first point is that representations can improve computational efficiency (Larkin & Simon, 1987) by making features more easily recognizable, making information more explicit, searchable, or interpretable. The second point is that representations can improve domain learning characteristics (Cheng, 1999) by providing the learner with an external representation that encodes all relevant features of a problem space and helping to promote the integration of those features. Table 1, below, is adapted from and extends (Woods, 1994) and presents a set of core performance and learning issues that can be supported by carefully constructed representations.

Internal Representations

The external visual representations described above are directly related to human internal representations, also known as mental models or schema. There is a core relationship between human internal representations and external representations of problem areas. This relationship has three principle components (Norman, 1983):

- Belief System: The belief system that forms the schema has been acquired through observation, instruction, or inference.
- Observability: There is a correspondence between parameters and states in the humans' schema and the parameters and states that the human can observe in the external world.

Table 1. Value of external representation in human task performance and learning

Task Performance or Learning Issue	Value of Representation
1. Problem Structuring	A good external representation is constructed in a form that allows different strategies to be used. For example, maps are structured to allow spatial calculations such as relative distance and areas of effect to be made easily.
2. Overload/workload	A good external representation reduces or attenuates cognitive effort by allowing processing that may be parallel, perceptual, or reentrant. In addition, a good representation can reduce demands on memory or dependencies on attention.
3. Control of Attention	A good external representation can draw attention to specific regions of the representation to support important data properties. A good external representation can also hold a viewers attention, allowing them to conduct more in depth analysis.
4. Secondary Tasks	A poor representation can create unnecessary secondary tasks, such conversions between scales and correlating with unrepresented data ranges. A good representation can create or allow beneficial secondary tasks that might be skipped, such as consistency and cross-checking results.
5. Effort	A good representation can reduce effort for a specific task-context.
6. Communication & Coordination	A good representation allows others access to the problem solving process and intermediary results.
7. Guided Interpretation	A good representation supports the range of valid interpretations that can be made of a set of information and does not support improper interpretations

- Predictive Power: The purpose of the schema is to enable limited prediction of future states and parameters. The model learned by the human must therefore be able to be used to generate useful predictions. By implication, the external belief system the human is engaged with must be structured to support the same predictions and to enable the human to make those predictions.

For example, the Course of Action graphic layers a complex information graphic on top of simple, stylized, map depiction. The authors and readers of this diagram need specific training to understand the syntactic content of the individual pictograms and the semantic meaning of their relative locations on the base map. The graphic presents a specific class of tactical mission pictograms that mark the location of concrete objects, including friendly units and town locations, abstract geographic areas, such as objective areas, and abstract process flow indicators, such as advance and reconnaissance arrows and lines of advance. This graphic both reflects and informs how the military understands Courses of Action and the critical behaviors of Army units and renders the graphic authors understanding of the current world and possible future world explicit and observable. The graphic has a strong spatial and temporal orientation, articulating the behavior of entities over time and space. The graphic only reflects intent, however, and not a scripted reality. COA diagrams, therefore, have only a limited predictive power, but a strong interpretive and communicative power.

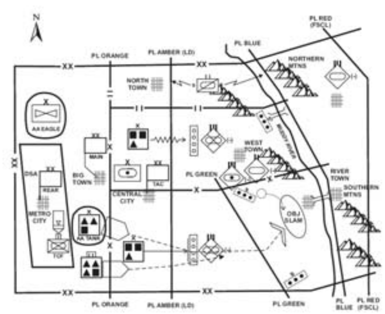

Figure 1: Course of Action Sketch overlays map depiction with military operational graphics

One critical point is that schemas are not simply internalized versions of external representations. Schemas are flexible and active, automatically filling in missing information, generalizing from the past. They are continually modifying and adapting interpretive states (Norman, 1986) that guide how we think understand our environment. These correspondences, then, apply broadly to the entire environment and not just to visual representations. In the COA example, a trained reader can identify detail not available in the external representation and apply general knowledge to fill in those gaps.

The impact on visual representations is clear: external representations must support the construction of mental models with appropriate expressiveness and predictive power. A COA map that expresses historic meteorological data but not planned actions would not be appropriate. In addition, external representations must provide indicators of current parameters and states in a manner that corresponds with that model. Finally, the external representation must support the interactive construction, modification, and interpretation to support the performance and learning issues described above.

There is a large challenge, then, in designing external visual representations that have the right mix of concrete depiction and abstract graphics laid out in a manner that supports the right class of calculations, search and inferences and populated with data that properly reflects the external and internal worlds. Table 1 lists a number ways that external representations impact task and learning performance. The implication of this list is that task specific representations better mesh and support schemas and improve task and learning performance. The challenge, then, is to ensure that a human engaged in a performance or learning task either has or can construct an appropriate external representation.

Basic Skills

In pursuing this research we have developed a set of basic skills that are required to support the construction and usage of external representations (see Table 2) and their positive usage in internal model formation and decision-making (see Table 3. These skills, we believe, are trainable in a general way that will support transfer of skill across a range of tasks and technologies. Training these skills requires a focus on the information and computation needs of the task in question and understanding the nature of visual grammar such that representations can be constructed that meet these requirements.

Table 2: External representation construction skills

1. Identify their current information needs
2. Select an appropriate visual artifact
3. Interpret the artifact, determining:
    - What classes of information it contains
    - What classes of inference it supports
    - What classes of information and inference are *not supported*
4. Manipulate the artifact to put it in a state that enables the desired information to be extracted and inferences made

Table 3: Internal schema construction skills

1. Extract relevant information from the prepared visual artifact
2. Convert the information into a form that fits their existing mental schema, including:
    - Transforming information from one representation or orientation into another
    - Aggregating discrete information chunks
    - Refining the existing schema (as necessary)
3. Draw inferences from new knowledge to support decision-making process

Visual language theory suggests that humans process diagrammatic graphics in a manner similar to natural language and that visual languages, including all the graphics examples above, have similar structure including a visual syntax, semantics, and pragmatics (Narayanan & Hübscher, 1998). Syntax describes the grammatical form of the language: what elements it contains and how those elements are structurally organized. Semantics describes how statements made with the language are interpreted, and what interpretations are valid. Pragmatics describes how we can use the meaning of the statements to achieve specific goals.

For an example, consider the MOUT Intelligence Preparation of the Battlefield incident overlay map below (Medby & Glenn, 2002, see Figure 2.) Proper interpretation of this map requires a thorough knowledge of the syntax, semantics, and pragmatics that were assumed in its construction. The map syntax defines:

- *The type of marks used to encode roadways of different sizes*, i.e. lines of different weights where an increase in weight corresponds to an increase in road carrying capacity and/or lane size.
- *The types of marks used to encode roadway names and roadway types*, i.e. full text of a specific size to note urban streets and larger text in a circle to note a highway system.
- *The types of marks used to encode incident data*, i.e. ● for ambush, ★ for bombing, ☐ for murder, and ○ for kidnap.

The incident overlay map semantics shows that there are twelve individual incidents in this region in the time frame recorded and that there is one cluster of bombings, one cluster of murders, two clusters (or one large cluster) of ambushes and kidnaps. The map pragmatics supports historic functions, including the recording of incident data and analytic functions, including the identification of incident locations and incident patterns.

It is equally important to understand what the visual language used in this map does not support. While the map implies that it records incidents over a limited period of time, the map syntax does not provide any marks that would date the individual incidents in the map or the duration of time covered by the map itself. From a semantics perspective then, it is impossible to extract temporal patterns, such as inferring the direction that the bomber might be moving through the city. From a pragmatics perspective then, this map is inappropriate for identifying temporal patterns.

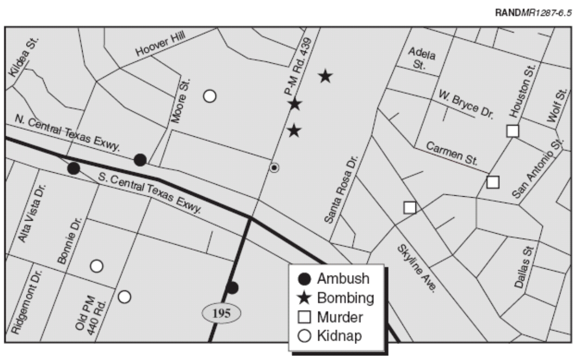

Figure 2. MOUT Incident Overlay Map

Pedagogical approach

Social constructivism

The social constructivist approach to educational technology is the basis for many current educational approaches in science (Singer, Marx, Krajcik, & Clay Chambers, 2000). The underlying theory about how people learn has two important pieces. First, the social piece asserts that "knowledge is… in part a product of the activity, context, and culture in which it is developed and used" (Brown, Collins, & Duguid, 1989). This contextualized view of knowledge implies that learners must participate in social context that reflects the culture of the practice. Second, the constructivist piece asserts that learners must be actively engaged to make cognitive connections between their existing knowledge and that being learned (Papert, 1993; Piaget, 1954).

Because constructivism is a "theory of knowing" and not a "theory of teaching," there is no one specific constructivist approach (Bransford, Brown, & Cocking, 2000). As a result, the products of the social constructivist approach are complex learning environments rather than specific types of instructional systems. Learning environments can include multiple components that work together to support the learner as they mindfully engage in and learn a new practice. Wilson (1996) defines such an environment as: "a place where learners may work together and support each other as they use a variety of tools and information resources in their guided pursuit of learning goals and problem-solving activities."

Depending on the context of the targeted practice, these goals may be instantiated in a variety of ways, leading to learning environments that look very different on the surface. A learning environment may be comprised of multiple components (e.g., teacher, curriculum, and ITS) that work together to support and guide the learner. Although it is possible to construct a learning environment that does not incorporate technology, it is more practical to include technology so that the goal of one-to-one instruction can be more readily realized.

The social constructivist approach allows one to tackle more open-ended and exploratory tasks than either the behaviorist or information processing approaches. The very nature of these open-ended and exploratory tasks, however, requires the development of more complex cognitive processes on the part of the learner. Considering the potentially great gap between the novice learner and the targeted practice, significant structure and support is needed for the learner to effectively engage in the new practices.

Scaffolding

In all of the approaches to educational technology described above, learners are faced with novel tasks that are beyond their abilities. The educational technology is designed to support the student, providing a "scaffolding" to enable learners to successfully perform tasks that would be otherwise be too difficult (Wood, 1976). While scaffolding is important for a novice, it can become a hindrance to more advanced learners. Pea (2004) points out that "fading" is a fundamental aspect of the scaffolding process as an instructional strategy. If the supports provided to the learner do not fade over time, the learner may become reliant on them and never achieve autonomous performance that is the goal in an instructional setting. There are no specific prescriptions for how to implement scaffolding. Specific design decisions must be based on context and an analysis of the learner's obstacles. Scaffolding can be incorporated in any kind of educational technology.

Self-explanation

As discussed previously, it is important for learners to be involved in the construction of their knowledge. That is, they must be actively engaged during learning so that cognitive connections can be made between their existing knowledge and the knowledge being acquired.

Self-explanation is a domain-independent, meta-cognitive skill that directly engages learners in active knowledge-building. The act of self-explaining involves generating explanations to oneself in an attempt to make sense of new information. This new information may be presented in text or in some other medium like a graphical representation or the solution to a problem.

When learning a new skill, the use of examples can be very helpful. The benefits of learning from examples, however, depend strongly on how they are studied. Studies show that students who spontaneously self-explain while studying examples learn more (Chi et al., 1989). In addition, self-explanations are more effective than explanations provided by others because (Chi, 2000) (a) they engage learners in more constructive learning processes by requiring them to bring to bear and actively elaborate their existing knowledge and (b) learners self-explain to address their own specific difficulties in understanding whereas explanations produced by others are not necessarily tailored to individual learner needs.

Despite the benefits, the studies also show that most learners do not spontaneously self-explain. They will self-explain more when guided (Bielaczyc et al., 1995) or prompted to do so (Chi et al., 1994). As Conati & VanLehn (2000) point out, this makes a strong case for explicitly coaching self-explanation in a training system that supports problem solving and learning from examples.

CURRENT WORK

Training tasks

We are organizing training materials into four discrete modules that link the instruction directly to operational tasks. These modules can be viewed as questions the trainee would like to answer regarding visualization as follows:

1. *What do I need to do?* – This module focuses on the operational task or subtask, key decision points, and necessary situation awareness skills for making those decisions. While there may be pointers to other background material, the focus will be on those aspects of the training task that relate specifically to visualization.
2. *What do I need to know?* – This module focuses on information requirements for successfully completing the task and helps the trainee develop an appropriate mental model of the required information requirements for the operational decisions.
3. *How do I obtain and construct the information I need?* – This module focuses on available sources that can provide the required information and techniques for organizing information and creating effective visualization artifacts. A key part of this module is understanding the strengths and weaknesses of different representations of the necessary information and criteria for selecting which to use when several may apply.
4. *How do I use visualization artifacts?* – This module focuses on how to effectively use visualization artifacts once they are constructed. It includes the time quality and uncertainty of visual information and how to effectively maintain and utilize specific artifacts to accomplish the operational task.

The described training tasks discuss an approach to visualization that is centered on the trainee warfighter need. This approach also suggests several training objectives that focus on the trainer's perspective. These objectives include (a) enabling the trainee to learn select general visualization skills that will transfer to an evaluation situation involving similar tasks and representations; (b) enabling the trainee to gain the ability to perform select visualization tasks in a realistic context without the support of the training system; and (c) enabling the trainer to define, control, and maintain consistency of training delivery across trainees and course modules.

Basic skills part-task trainer

Meeting the training objectives described above requires researching and developing a part-task visualization trainer. This software system would support individual trainees in developing basic visualization skills; such as representation reference mapping, pattern detection, scene change detection, and other skills necessary for situational assessment and perception of relevant data. This trainer would use the underlying visualization system to provide basic visualization support and as the basis for a tutorial dialog with the trainee. This dialog would interactively explain visualization rational, suggesting visualization configurations, and providing problem-solving hints. This interaction would be structured as an educational scaffold, allowing specific supports to be removed as trainee skill and confidence increases. The supports are gradually faded as the trainee gains skill and confidence. The ultimate goal is for the trainee to perform without the supports of the system. The notion of "fading" is also part of the cognitive apprenticeship model (referred to in the previous section). The model suggests a gradual removal of supports during instruction so that the trainee gradually assumes more and more responsibility, ultimately performing independently. This enables the trainee to approach the target skills by successive approximation, thus allowing them to perform as much of the work as they are able while the training system ensures that they stay on track (Anderson et al., 1995).

Training Focus

The trainer will stress individual student interaction with the training tool in the context of a larger military training course such as the Intelligence Preparation of the Battlefield lesson from Army Training Circular TC 7-98-1 "Stability and Support Operations Training Support Package" (Department of the Army 1997). During this interaction, the student would be presented with a series of training exercises that would develop basic external-artifact based visualization skills, including:

- Visual Image Comprehension: Develop basic rules of visual language by presentation and examination of standard military visual representations (such as Course of Action map) focusing on what is expressible by and interpretable from these representations and visual representations in general. For example, standard MIL-SPEC-2525b C2 symbology can represent locations of enemy units, including a range of unit characteristics, but cannot (by itself) represent the degree of certainty in the assessment of unit type or time since last verification of unit position.
- Visual Image Development: Develop basic rules of visual image construction focusing on translating a specific information or communication need into selection of appropriate visualization representations or projections based on the characteristics of their visual language. For example, choosing between 2D and 3D images and choosing appropriate display layers (built features, terrain features) and layer configurations requires understanding what which representation feature are required to articulate a particular concept or intent. For example, Intelligence Preparation of the Battlefield and CCIR recognition have different requirements for representing sensor capabilities and coverage.
- Pattern Detection and Situation Identification: Develop basic skills in techniques selection, alignment, and annotation to create frames of reference across multiple images or data sets relative to a particular area of interest. For example, using a time series of satellite images to identify newly constructed barricades, sniper positions, or possible Improvised Explosive Device (IED) locations.

Training Curriculum

The training methodology we are developing will include a series of modules relating to external representation and internal scheme construction specifically targeted for MOUT cordon and search operations. What follows is an instructional example of our proposed methodology.

Full-Task: Cordon and Search Mission Planning

While our methodology and computer-based training modules will be part-task, they will always be situated in full decision-making task contexts. For example, a central task in cordon and search mission planning is selecting safe ingress and egress routes. Ingress and egress routes are critical to prevent platoons or squads from being cut off and isolated, thus vulnerable to insurgent attacks.

Part-Task: Cordon and Search Visualization

Selecting routes requires developing a battlefield visualization that integrates a number of features including identifying likely sniper locations and ground locations particularly vulnerable to insurgent attack. The information that supports this visualization task comes from a variety of sources including maps and satellite images, historical reports and current SITREPS, interviews with locals and reconnaissance photographs. Important sub-tasks include identifying locations with high elevations and wide fields of observation and fire.

Trainee Tasks

In this example, the trainee would work with the computer-based trainer to create a visual representation that supports critical inferences generation and pattern detection. This process might include (a) selection of a base visual projection. (In this example, the trainee might select from 2-D geospatial maps and medium resolution satellite image, neither of which would show elevation data clearly.); (b) addition of data points including building elevation data, reports of sniper positions and historic sniper kill locations; (c) selection of visual representations and features to facilitate pattern detection; (d) identification of buildings with dangerous fields of observation and fire; (e) annotation of these buildings with sniper pictograms; and (f) manual calculation of line of sight and identification of regions and routes that fall within and without likely sniper line of sight.

Computer-Based Training Tool Support

To facilitate the trainee in accomplishing these tasks the part-task trainer will need a set of basic visualization capabilities including (a) selection between base projections, (b) addition of data points, both manual and from provided data set, (c) mapping data points to visual representations (standard military standards such as MIL2525b and FM 101-5-1 and nonstandard representations when needed), and (d) annotation of resulting representation with trainee marks to support calculations, note, and place keeping

Instructional Strategy

The part-task trainer will provide also a set of scaffolded instructional aids that will fade out as the trainee progresses toward module mastery. Early in training these might include (a) free exploration of representational features; (b) identification of intended inferences and pattern features relative to the instructional task; (c) forced self-explanation of representational choices relative to intended inferences and pattern features; (d) automatic feedback to guide or correct representation selection. Later in training these might include (a) final representation evaluation; (b) quizzes to force trainees to use their created representation for inference generation or pattern detection and (c) use of forced-self explanation to support quiz review and feedback.

Training evaluation

Evaluating training effectiveness is a critical component in the development of a training curriculum, helping to gauge the effectiveness of the training material and training mechanisms (a summative *effects of* evaluation) and providing guiding feedback to the research and development process (a formative *effects with* evaluation). As critical as they are, evaluations of training systems are notoriously difficult to perform rigorously. An ideal evaluation would compare student learning with the newly-developed training system to student learning with traditional methods. This would evaluate student mastery of training objectives and their ability to put these skills into practice. Ideal evaluation would also have enough controls to ensure any differences observed in the effects-of evaluation could be attributed to the training techniques and materials.

Achieving an evaluation of this type in a rigorous manner is beyond the scope this project, and most projects involving military training. We will work with the client to develop a concrete evaluation plan that provides initial feedback on the effectiveness of the techniques and materials being explored.

We will evaluate military students' learning (effects of training) by comparing performance on pre- and post-tests. Students engaged in standard military training will be used as a comparison group. Their performance on pre- and post-tests will also be measured. Learning gains for the two groups can then be compared.

More detailed process data will be collected during individual observations of students during training. These observations will provide important information about how the students interact with the training system and where they have difficulty. Think-aloud protocols and a modified form of the SAGAT protocol (e.g. Endsley, et al., 2000) will be used to record students' thinking and probe their knowledge as it develops during training. This effects-with data will also help to explain learning gains measured by the pre-/post-tests.

Finally we will conduct a controlled lab study with non-military students. Because these students will not have the prerequisite military knowledge for the training, they will be used mainly to document how well the training supports the development of specific visualization skills. It is unlikely that these students will be able to coordinate the basic visualization skills in the context of the broader Cordon and Search task, therefore the pre- and post-testing will not be on the scale of the broader task, but will focus on visualization skills within individual training components.

SUMMARY & CONCLUSIONS

MDMP requires that commanders be able to integrate and visualize a wide range of information. This information is drawn from a wide range of information sources, ranging from satellite images to verbal reports to direct visual observation. Mental integration of this information is often contingent on the commanders ability to manage external visual representations, whether supported by the latest C2 display, grease pencil and acetate sheets, or a patch of wet sand and a stick. It is our contention that the skills required to construct external visual representations and relate them to internal schemas can be taught and the basic visual grammar skills are applicable across a wide range of visual representations.

Training these skills requires the development of course material that isolates the visual knowledge management tasks from the complex decision-making tasks that define their context and focus on the development of basic visualization skills. It also requires computer-based instruction software that, though scaffolded lessons and guided self-explanation, enables the student to engage in these part-task lessons in a manner that facilitates learning and reduces training costs. This approach will represent a significant step forward in digital instruction technique and product.

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