

Shaping Mental Models of the Scenario-based Training Process: A Preliminary Validation Of Shipboard Instructor Training

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Abstract

A current philosophical trend in Navy training is to place less emphasis on traditional shore-based training and more on shipboard training. While many technological advancements help achieve this goal (e.g., embedded training), a lack of adequately trained instructors represents a potential problem to shipboard training. Shipboard instructors must manage the scheduling and conduct of a complex web of interconnected training exercises designed to meet learning objectives for multiple teams, as well as individual-level objectives for specific watchstanders. All this takes place within a functioning operational environment where task requirements compete with training demands. In order to provide meaningful, coordinated instruction in this environment, instructors must have a clear understanding of the instructional processes involved. A one-day instructor workshop was conducted in order to shape instructors' "mental models" of the scenario-based training cycle. As part of an effort to validate this training, we examined changes in the mental models of 17 shipboard instructors from a pre-commissioned ship using a concept ordering task before and after the training workshop. Using these data, instructors' mental models were compared to an expert's model (i.e., the course developer) in order to validate the training received. Results are discussed in light of mental model theory as well as the demands of shipboard instructor training.

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Introduction

The Navy continues to rely more and more heavily on shipboard training to impart both individual technical training as well as advanced training on team skills. Current trends in training policies indicate that shipboard personnel will arrive for their first deployment with less baseline knowledge than in previous times. Therefore, shipboard instructors must provide training on basic skills that were previously covered in shore-based training. This places increased burdens on shipboard instructors who often come to the job with little, if any, experience as a trainer. Shipboard instructors must manage the scheduling and conduct of a complex web of interconnected training exercises designed to meet learning objectives for multiple teams, as well as individual-level objectives for specific watchstanders. All this takes place within a functioning operational environment where task requirements compete with training demands.

In such a complex environment, it is easy to see how the instructional process can be lost in a sea of seemingly endless checklists. Shipboard trainers, who are generally assigned on the basis of expertise as a watchstander rather than expertise as a trainer, receive very little guidance on understanding the underlying instructional goals of the shipboard training process. The highly proceduralized instructions given to shipboard training teams tends to foster rote adherence to rules and regulations, rather than conceptual understanding of the components and interdependencies within the scenario-based training cycle. Thus, many fail to see the big picture as they go through the motions of repeated scenario-based exercises.

An accurate mental representation, or “mental model”, of the scenario-based training cycle should aid shipboard instructors in providing meaningful,

coordinated instruction. The term “mental model” is often used to refer to knowledge structures or schemata which humans use to organize knowledge (Gentner & Stevens, 1983; Rumelhart & Ortony, 1977). Researchers in several disciplines (e.g., cognitive psychology, human factors, cognitive science, educational psychology) have hypothesized that individuals use these dynamic cognitive representations to describe, explain and predict events (Rouse & Morris, 1988). Thus, mental models are expected to guide human interaction with their environment.

We argue that shipboard training teams require instruction which shapes their mental models of the scenario-based training cycle. This paper reports preliminary data suggesting that such mental models can be shaped through deployable instructor training. First, we will describe a model of scenario-based shipboard training which was the focus of a one-day workshop. Second, we will discuss methods of measuring training induced changes in mental models. Third, preliminary results from a shipboard validation study of scenario-based instructor training will be reported. Finally, implications and directions for future research will be discussed.

A Model of the Scenario-based Training Cycle

Scenario-based shipboard training involves active practice in simulation exercises which are embedded in a ship’s operational system (e.g., combat systems). Such training is designed to prepare sailors to perform their tasks in a variety of situations they may potentially face at sea. Scenario exercises, in this case, are the training curriculum. The selection of training scenarios should be based on deficiencies observed in previous exercises. Thus, scenarios serve the purpose of providing both active practice and an opportunity to assess training needs. In order to accomplish effective training, these scenarios must

be linked together in a meaningful way by (1) prebriefs which situate trainees for a particular mission and focus their attention on desired learning objectives, (2) instructor observation, (3) diagnosis of performance deficiencies, and (4) developmental feedback provided during post-exercise debriefs. Each of these components of the scenario-based training cycle, depicted in Figure 1, are described in greater detail in the following sections.

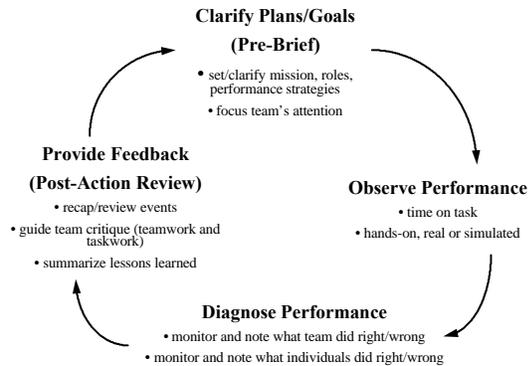


Figure 1. Team Learning Cycle

Prebrief

An effective prebrief prepares trainees to learn from a particular scenario exercise. This includes, first, situating them in their simulated environment by providing information about things such as the particular part of the world they will be in, the time of year and time of day, weather conditions, geopolitical environment, rules of engagement (ROE), status of their ship's equipment and personnel, and mission goals.

Second, an effective prebrief focuses trainees on the particular learning objectives to be accomplished in a scenario. These objectives should be based on training requirements and deficiencies observed in previous exercises. Thus, lessons learned and goals set during previous post-scenario debriefs should be highlighted during the prebrief.

Third, the prebrief provides instructors with an opportunity to establish a positive climate for team learning. This involves encouraging team members to ask questions and offer suggestions and comments.

Observe Performance

The next stage in the scenario-based training cycle involves observing and recording actions taken by trainees during a scenario. Instructors should be trained to look for instances of both effective and ineffective performance that are relevant to learning objectives.

Pre-scripted scenario events can be used to elicit performance examples which allow instructors to evaluate an individual or team's knowledge or skill in a particular area. These scenario events help instructors to identify a representative sample of performance instances which can be used for diagnosis and feedback.

Specific examples should be recorded rather than general impressions or frequency counts of errors observed.

Diagnosis

After an exercise has ended, instructors must diagnose the causes of observed performance problems. In doing so instructors must identify the processes that led to performance outcomes. These processes should be the focus of developmental feedback provided in a post-exercise debrief (Smith-Jentsch, Johnston, & Payne, in press).

It is important that instructors diagnose processes that will lead to effective outcomes in a variety of situations, rather than becoming preoccupied with the outcome of a particular training scenario. Moreover, individual and team level strengths and weaknesses must be distinguished. For example, a team may make an incorrect decision because information was not circulated effectively among team members. On the other hand, the same incorrect decision may result if information is circulated appropriately, but the information was incorrect to begin with as a result of a technical error made by an individual. In the first case, team training which focused on information exchange may be appropriate remediation, whereas in the second case a single team member may require additional technical training.

Another way of labeling the distinction between individual and team processes is to talk about

“teamwork” versus “taskwork” (Cannon-Bowers, Tannenbaum, Salas, & Volpe, 1995; Cannon-Bowers & Salas, in press). Taskwork can be thought of as the requirements of one’s job that are position-specific and usually technical in nature (e.g., the ability to interpret a radar display, buttonology, knowledge of rules of engagement). Teamwork, on the other hand, includes processes that individuals use to coordinate their activities (e.g., communication).

Debrief

Developmental feedback is provided to trainees during the post-scenario debrief. Feedback sessions which allow for active participation of trainees have been shown to be more effective than those involving a one-way dialogue from instructor to trainees (Smith-Jentsch, Payne, & Johnston, 1996). However, the instructor must guide the team toward discussing aspects of their performance that are relevant to learning objectives.

In order to help teams get started with such a process of “guided team self-correction” an instructor should first recap key scenario events. Both team and individual debriefing sessions should include a goal setting which targets observed deficiencies. These goals then become the learning objectives for subsequent scenarios.

Measuring Changes in Structural Knowledge

The previous sections describe a model of the scenario-based training cycle. We have argued that shipboard instructors often do not understand this cycle and that the quality of training they provide suffers as a result. Thus, a one-day workshop was developed to attempt to improve instructors’ understanding of the scenario-based training cycle. As a preliminary validation of this training we examined pre-post changes in instructors’ cognitive representations, or mental models.

A mental model is a construct used to describe the manner in which individuals organize their knowledge in memory.

Previous research has shown that experts and novices differ considerably in the manner in which they organize knowledge in memory. For example,

Chi, Glaser, & Reese (1982) found novice mechanics problem solvers grouped problems based on surface features such as the appearance of pulleys or inclined planes. Experts, on the other hand, classified problems based on categories of solutions or mechanical laws, such as Newton’s laws of motion.

Similarly, Chi, Feltovich, and Glaser, (1981) examined the differences in the ways expert and novice problem solvers represent physics problems. The authors found that while experts and novices categorize problems in a meaningful way, novices use surface features as a basis for categorization while experts categorize problems based on underlying principles governing solutions.

Given that experts and novices differ in the way they organize knowledge, one metric used to examine training-related changes in structural knowledge is to measure the extent to which an individual’s knowledge is structured more similarly to an expert’s knowledge structure after training. Structural assessment is an evaluation technique used to make this comparison (Goldsmith & Kraiger, 1997).

Structural assessment first involves defining the domain by identifying critical terms or concepts. These terms are then used to elicit an individual’s judgments of relatedness among the terms. These judgments can be used to create schematic representations of an individual’s knowledge structure and can be qualitatively compared to an expert’s representation. The extent to which an individual’s knowledge is organized similar to that of an expert’s can be quantitatively measured by statistical evaluations which compare the overlap of an individual’s representation to that of an expert.

In this study, 33 terms related to the scenario-based training cycle were selected to serve as the domain of interest. While a variety of elicitation techniques exist (i.e., similarity judgments and card sorts), the method used here required individuals to perform a concept ordering task using the selected terms. Data from the concept ordering task were used to produce ‘ordered tree’ representations (Reitman & Rueter, 1980) as well as link-weighted networks (Schavandeveldt, 1990). Ordered tree representations provide a hierarchically nested structure that captures the groups of concepts, or chunks, that regularly appear together. Pathfinder

Nets, or pfnets, provides a network representation of linkages between the concepts. Data were also used to derive evaluations of similarity to an expert's organization by using Pathfinder analyses (Schvandeveltdt, 1990) and ordered tree analyses (Hirtle, 1982).

Research Questions

It was hypothesized that the instructor training workshop would shape trainees' mental models of the scenario-based training cycle. Specifically, we expected that instructors' mental models would become qualitatively and quantitatively more similar to the trained model following the instructor workshop.

First, ordered tree representations and pfnets were expected to show noticeable qualitative improvement in knowledge organization when viewed with respect to an expert referent structure. Second, ordered tree and Pathfinder analyses were expected to show quantitatively that instructors representation of the scenario-based training cycle included more links in common with the trained representation following the workshop.

Method

Participants

Participants were 17 shipboard instructors from a pre-commissioned Navy ship. Of these, 15 were men and two were women. Eleven were members of the seamanship training team and six were members of the combat systems training team. These participants had varying exposure to the scenario-based training cycle; eight of the instructors had previously attended a related workshop.

Training

The instructor training workshop was designed to shape mental models of the scenario-based training cycle. First, this cycle, described earlier, was presented as an advanced organizer. Second, each component of the cycle was discussed in detail as well as relationships among components in a lecture/discussion format. Third, instructors conducted a series of training exercises using the suggested procedures described for each component.

Finally, instructors critiqued their own performance, and received feedback from the course instructor.

Measure

The concept ordering task included thirty-three concepts related to the scenario-based training cycle (see Table 1). Each instructor received a stack of 33 note cards which had the concepts listed on the front.

Table 1.

Terms/phrases used in concept listing task

Backup	Learning objectives
Brevity	Outcome
Buttonology	Passing information
Clarity	Phraseology
Communications	Prebrief
Completeness of reports	Process
Debrief	Providing guidance
Diagnosis	Recap of events
Error correction	Representative sampling
Exploiting sources of information	Scenario events
Feedback	Situation updates
Goal Setting	Specific examples
Guided team self-correction	Stating priorities
Information exchange	Supporting behaviors
Initiative/leadership	Taskwork
Knowledge of ROE	Teamwork
	Training cycle

Participants were asked to arrange the 33 concept cards in a manner such that each concept was followed by the concept they felt was most highly related to the previous card. Participants were instructed to repeat this procedure four times with a minimum of 15 minutes in between each ordering. Due to time constraints, not all participants were able to complete the concept ordering task four times. Thus, analyses were conducted using available data.

For two of the four concept ordering tasks, participants were allowed to begin with the concept of their choice. For the remaining two, one term was randomly selected and participants were forced to begin with that concept. This procedure is in accordance with previous research by Naveh-

Benjamin, McKeachie, Lin, and Tucker (1986). Distracter tasks were assigned during each 15 minute break in order to reduce the influence of rote memory from one trial to the next.

Procedure

Participants completed the concept ordering task the morning of the instructor training workshop. The workshop itself lasted eight hours. Participants repeated the concept ordering task the following morning as a post-test.

Results

Ordered Tree Analyses

The algorithm developed by Reitman and Rueter (1980) was used to create ordered tree representations for the pre- and post-training data of each participant. The mathematical foundation of this algorithm is a discipline called lattice theory, and the underlying psychological position is that knowledge is mentally organized in hierarchically connected chunks of related information. At an intuitive level, the top-down algorithm splits the entire series of concepts into the largest, non-overlapping groups of terms that appear together in every ordering and treats those groups as chunks. The algorithm then continues to repeat this process, breaking up the most recently delineated chunks into smaller chunks, until it has reduced all of the chunks to individual terms. The concepts are represented as the terminal nodes in a tree diagram, and different levels of hierarchical chunking are represented by intermediate nodes.

The Reitman and Rueter algorithm also distinguishes between (a) chunks which contain terms that can be accessed in any order, (b) chunks like the alphabet, which contains terms that are always accessed in one order, and (c) chunks like the numbers one through ten, which can be accessed in both forward and backward order. An example of an ordered tree can be found in Figure 2. This ordered tree is a representation of the expert referent structure that was created by the first author, who is one of the developers of the instructor training course and actually led the instructor training given in this experiment.

Qualitative Analyses. One important goal of measurement in a training context is diagnosis. When any technique for representing structured knowledge is used, the instructor must qualitatively examine the resulting representations and, interpreting as necessary, attempt to determine both the likely accuracies and likely inaccuracies in a student's understanding. In general, ordered trees are interpreted by examining the concepts that are connected by an intermediate node, and trying to determine what underlying reason a student might have for thinking that those concepts "go together."

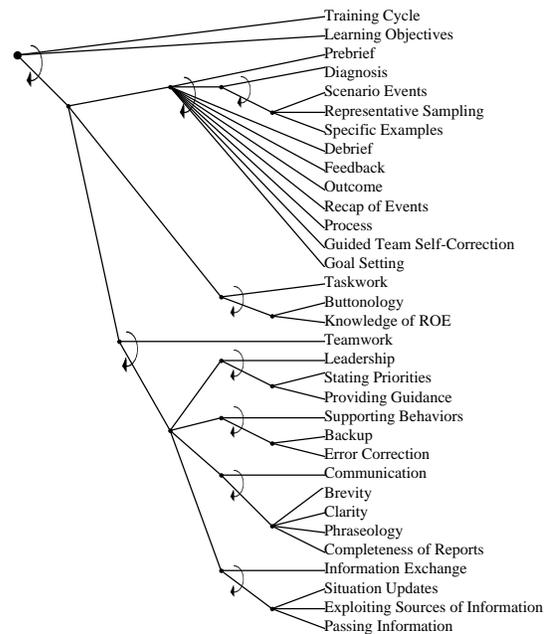


Figure 2. Expert/Referent Ordered Tree Structure

We will illustrate this process with the pre- and post-training ordered trees of one participant from this study, seen in Figures 3 and 4. These are rich representations that can be examined in great detail, but even a cursory comparison of the pre- and post-instruction trees to the expert referent structure shows dramatic improvement in several areas. The instructor training included two major components, the training cycle, and a set of behaviors associated with teamwork. In the pre-instruction ordered tree the concepts from these two components are mixed in together, but in the post-instruction ordered tree the intermediate nodes labeled A and D separate the concepts into sets based on those two components.

Other chunks within those two major chunks also show improved associations. For example, the training cycle chunk includes a smaller chunk that links the terms “representative sampling” and “debrief”. This association was not present in the pre-instruction tree, and suggests that the participant has learned the concept that an effective debrief can be based on a representative sample of team behaviors. Similarly, in the teamwork behavior chunk, nested chunks (intermediate nodes B and C) indicate that two of the teamwork dimensions and their associated behaviors are beginning to distinguish themselves from the general group of “all teamwork behaviors”.

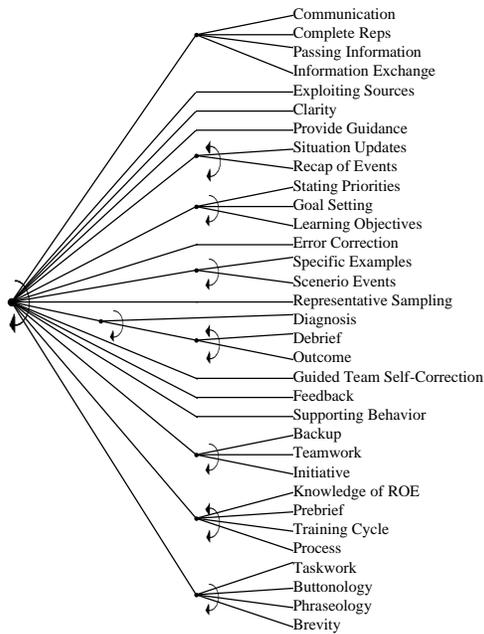


Figure 3. Example Pre-Training Ordered Tree

Quantitative Comparison to Expert. Hirtle (1982) described several methods for comparing two ordered tree representations and producing a quantitative measure of their similarity. The measure used in this study is determined by comparing the sets of chunks that are produced by each tree, and calculating the proportion of the chunks that the two trees have in common. Specifically, this is calculated by dividing the number of chunks that the two trees have in common by the total number of unique chunks that could be

produced by either tree, and applying a logarithmic transformation.

When the ordered trees for the pre-training data were compared to the expert’s ordered tree, the average similarity score was 0.0085 (sd=.013, n=17). For post-training data, the average ordered tree similarity score was 0.0119 (sd=.015, n=17). While this difference appears to be in the correct direction, a paired comparison test indicated that it was not significant.

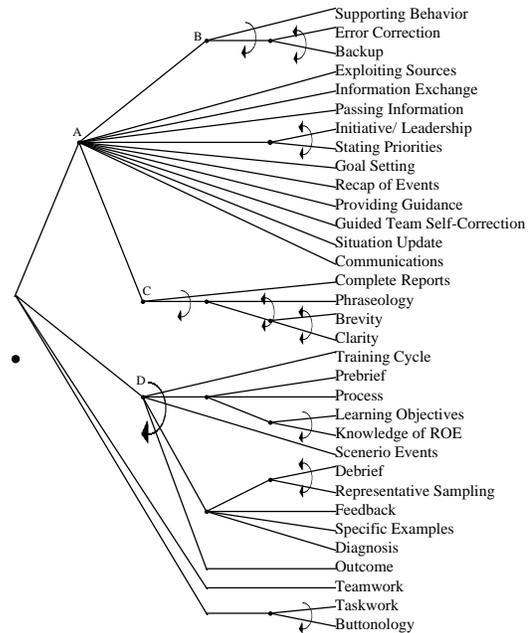


Figure 4. Example Post-Training Ordered Tree

Link-weighted Network Analyses

In order to produce the second type of structured knowledge representations, link-weighted networks, the concept ordering data were first transformed into a measure of pairwise similarity by calculating the average number of concepts that occurred between each pair of concepts across the multiple trials for each participant (Friendly, 1977). The resulting proximity matrices were then subjected to Pathfinder analyses to produce link-weighted networks. In a link-weighted network the concepts are represented by nodes, and the relationships between concepts are represented by links between the nodes. Intuitively, Pathfinder creates the network by first linking every

pair of concepts and associating a “length” with each link that is based on the amount of psychological similarity between that pair of concepts. Concepts which are highly similar are given short links and concepts which are not very related are given long links. Then Pathfinder goes through an iterative process in which it drops long direct links between pairs of concepts if there is a shorter, indirect route.

For this experiment, the parameters of the Pathfinder algorithm were set to $r=\infty$ and $q=32$ (the number of concepts minus one), which produces the least dense (i.e., fewest links) network and makes only ordinal assumptions about the data. An example of a pathfinder network (pfnet) can be found in Figure 5. This pfnet is a representation of the expert referent structure that was created by the first author.

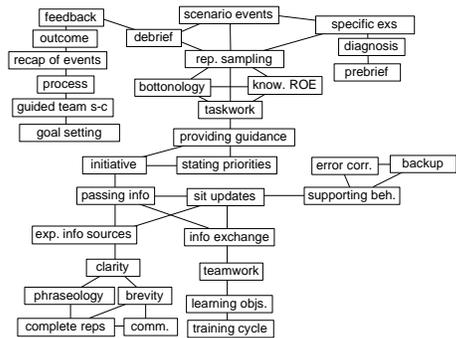


Figure 5. Expert Pfnet Representation

Qualitative Analyses. As with the ordered tree representations, any diagnosis of student understanding requires that individual pfnets be examined qualitatively. Interpretation of a pfnet must be done on a link by link basis, with each link indicating that the participant believes that those two concepts are related in some meaningful way. It should be noted that this requires a good deal of inferencing on the part of the analyst. In fact, a study which compared pfnets to concept maps (the product of a task which essentially asks people to hand draw their own pfnets and label the links) found that there were many instances in which novices and experts had the same pairwise links in their pfnets, but an examination of their concept maps indicated that the novices did not understand the nature of the relationship between those two

concepts, and sometimes even linked them for incorrect reasons (Dorsey & Foster, 1996).

We will illustrate this process with the pre- and post-training pfnets of one participant from this study, seen in Figures 6 and 7. As with the ordered trees, the pfnet of this participant becomes more similar to the instructor’s pfnet after the training. For example, the post-training pfnet (Figure 7) shows a clear grouping of behaviors associated with communication (i.e., phraseology, clarity, brevity, and completeness of reports). These associations are not demonstrated in the pre-training pfnet for this individual (Figure 6). Additional examples of correct associations can be seen in the post-training pfnet in the organization of taskwork concepts (i.e., knowledge of ROE and buttonology) and concepts related to information exchange (i.e., situation updates, exploiting sources of information and passing information). Again, these associations are not demonstrated within the pre-training pfnet.

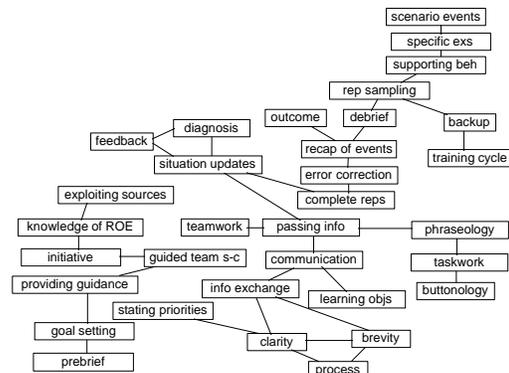


Figure 6. Example Pre-Training Pfnet

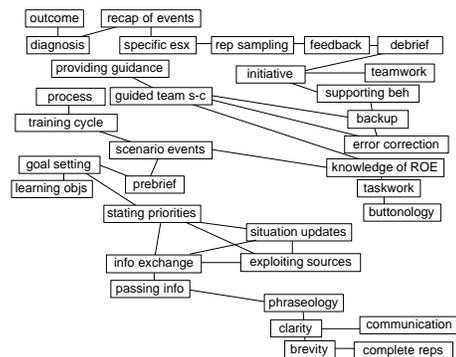


Figure 7. Example Post-Training Pfnet

Another Quantitative Comparison to Expert. After the matrices had been analyzed with Pathfinder, each individual's link-weighted networks (pre and post) were compared to that of the expert's using the Pathfinder Closeness algorithm (Goldsmith, Johnson & Acton, 1991). Like the approach for comparing ordered trees, this algorithm calculates the proportion of links that two networks have in common and can take on values from 0 (no links in common) to 1 (all links in common).

When the Pathfinder networks for the pre-training data were compared to the expert's network, the average Closeness score was $C=0.102$ ($sd=.044$, $n=17$). For post-training data, the average Closeness score was $C=.133$ ($sd=.038$, $n=17$). Paired comparisons showed a significant difference in pre-post Closeness scores [$t(16) = -3.48$, $p < .05$]. In other words, participants link-weighted networks had significantly more links in common with the expert's network after training than before.

Discussion

Effective shipboard training requires that instructors manage prebriefs, scenario events, performance diagnosis, and debriefs in a coordinated fashion. However, shipboard instructors receive very little training which prepares them to fill this role. Thus, we have argued that these instructors could benefit from training which shapes their mental models of the scenario-based training cycle.

We have described a model of this cycle which was the focus of a one-day shipboard instructor training workshop. Preliminary results suggested that participants' mental models became more similar to the trained model after the instructor training workshop.

Inspection of post-training ordered trees clearly indicated, for some instructors, the presence of concept groupings consistent with the expert model which were not present at pre-test. These results were seen most clearly as intermediate nodes delineating specific groupings. These groupings help to narrow potential interpretations more than the pairwise links in a pfnet.

The results of quantitative analyses comparing pre-post similarity to an expert solution were mixed.

Significant training-related improvement was found on pfnet similarity, however ordered tree similarity scores did not show significant change. Several factors may be responsible for the nonsignificant change on ordered tree similarity scores.

First, not all instructors were able to complete four trials of the concept ordering task. This may have had a greater impact on the reliability of ordered tree representations than pfnets.

A second possibility may be that ordered tree representations are less sensitive to changes brought on by the instruction.

Finally, this study was conducted with a relatively low number of participants. Thus, it may be that quantitative analyses involving ordered tree representations simply lacked statistical power. Certainly, further research is necessary to replicate and extend the findings described here using a larger number of instructors.

However, these results provide preliminary evidence that instructor mental models can be shaped by a relatively brief training intervention. It is possible that the benefits of this type of training may actually increase as instructors acquire additional hands on experience as a shipboard instructor.

The workshop itself was designed to provide an advanced organizer which would allow instructors to make sense of the complex shipboard training environment. It is hoped that participants will use the model presented in training as a framework from which to build a richer representation of the complex shipboard training environment as they gain experience as an instructor.

Future studies are needed to examine the long-term effects of such training, as well as to compare different strategies for assessing knowledge structures.

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