

A Cognitive Science Approach to Structuring Lesson Content

ABSTRACT

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A critical component of combat readiness lies in the skills and knowledge of the deployed personnel. However, these skills are highly perishable without continued training. Embedded training (ET) is one potential solution to the problem of maintaining a maximum level of operator readiness. The objectives of ET are to build on existing knowledge, diagnose and correct deficiencies as efficiently as possible, consolidate skills through practice, and acquire new knowledge and skills. ET effectiveness can be increased by implementing instructional technologies that promote efficient acquisition and retention of skills and knowledge. Current research on the application of cognitive learning principles to training provides precise instructional methods and implementation techniques. Recent research at the Institute for Simulation and Training (IST), in collaboration with the Naval Training Systems Center (NTSC), has demonstrated the power of this cognitive learning approach in applied Navy training environments. Significant improvements were found in the instructional capabilities of tactical console ET lessons.

The present effort involves evaluating this instructional methodology using a Computer-Aided Submode Training (CAST) lesson of the Navy's Aegis weapons system. CAST was selected because it provides an ideal environment for implementing cognitively-based instructional enhancements. It incorporates a well-developed ISD methodology, which provides a framework to build a more specific cognitive learning approach. A CAST lesson was restructured according to the cognitive task analysis methodology. Performance on the cognitive lesson was then empirically compared to performance achieved on the original lesson. Trainees receiving the cognitively structured lesson significantly outperformed trainees receiving the original lesson by an average improvement of 47%. These findings strongly support previous research concerning the merits of this cognitive approach to learning.

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A COGNITIVE SCIENCE APPROACH TO STRUCTURING LESSON CONTENT

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INTRODUCTION

A critical component of combat readiness involves the skill and knowledge levels of the personnel who must perform the specified missions. For Naval readiness, key personnel must competently operate sophisticated weapons, electronic warfare, navigational, and communications systems. In order to skillfully operate these complex systems, operators must be well trained initially, and they must receive frequent opportunities to practice and refine their skills. The cognitive and psychomotor skills needed to operate these devices are highly perishable, and without continued refresher training they will degrade rapidly (e.g., Massey, Harris, Downes-Martin, & Kurland, 1986).

On-board embedded training (ET) is one potential solution to the problem of maintaining a maximum level of operator performance and readiness. By building training capabilities into, or adding them onto, an operational system, operator skill proficiency can be maintained and enhanced in an accessible, high fidelity environment. In order to maximize training efficiency and retention, lessons should be structured to provide each trainee with the most learning gain from each training session. The goal of the ET session is to build on existing knowledge, to diagnose and correct deficiencies as efficiently as possible, and to allow for consolidation of skills through practice. The training effectiveness of ET sessions will be increased with the implementation of instructional technologies and strategies that promote efficient acquisition and retention of skills and knowledge.

Substantial cognitive science research has been directed at understanding the cognitive processes involved in knowledge acquisition and skill development. Learning to perform complex tasks, such as operating a tactical console, involves an active knowledge construction process, and this construction of new knowledge is highly dependent upon both existing knowledge and the situation or environment in which the learning takes place (e.g., Williams, Reynolds, Carolan, Anglin, & Shrestha, 1989). The cognitive model formed by this knowledge acquisition process is used in future interaction with the device. Cognitive science research has indicated that the underlying structure of this model is consistent with the framework of a production system (Anderson, 1983, 1986). A production system consists of a data base of facts, or declarative knowledge, and a set of productions, which are IF-THEN rules. This implies that if we develop instructional material consistent with a rule-based, production system approach, learning should be aided and improved, and the application of that learned knowledge will be facilitated.

Considerable research has been focused on the notion of a rule-based approach to learning. Nisbett and associates (Nisbett and Kunda, 1985; Cheng, Holyoak, Nisbett, and Oliver, 1986; Fong, Krantz, and Nisbett, 1986) performed a series of experiments which demonstrated that people are very good at abstracting rules from examples, as long as they can relate to those examples. Students were more likely to generalize and apply formal rules of logic to everyday problems when given

pragmatic examples from which to abstract the rules.

This rule-based approach to knowledge acquisition also emphasizes the importance of goals in a hierarchy of rules. The importance of goals in information processing can be seen in production models of cognition (Newell and Simon, 1972; Anderson, 1983; Holland, Holyoak, Nisbett, and Thagard, 1986; Klahr, Langley, and Neches, 1987). These models also address the importance of a hierarchical goal structure which guides processing. One important function of a goal is in directing attention. Research has also demonstrated that goals can set the speed of successful perceptions as well as what is perceived (La Berge, 1973; Posner and Snyder, 1975). In addition to the importance of goals in guiding attention and actions, a hierarchy of goals also plays a prominent role in memory organizations. Anderson (1983) has demonstrated the importance of a hierarchy of goals in guiding the development of rules (productions) and the creation of new rules by combining existing rules. Jeffries, Turner, Polson, and Atwood (1981) and Anderson (1986) have noted that by establishing a goal tree, the rules that are likely to be composed by students can be predicted.

The cognitive science research effort has led to the formalization of various learning processes and strategies. The application of research in cognitive skill acquisition has demonstrated the feasibility of the approach and its positive impact on the learning process (Anderson, 1983, 1986). For example, Chi and associates (1981, 1989) showed that good students are able to explain the conditions associated with a specific action, whereas poor students are not. Good students also generate more complete condition-action rules during the learning process. They construct such rules from the instructional material presented to them (Bovair and Kieras, 1990). Research demonstrates that learning is enhanced when material to be learned is formulated as production rules and presented to trainees as specific procedures during the training process. Reif (1987) found that this technique, when applied to basic science concepts, resulted in a 50% increase in learning.

A training methodology, developed by the Institute for Simulation and Training (IST) under

contract to the Naval Training Systems Center, based on this cognitive science research demonstrates the training improvements that can be achieved. Application of the methodology involves using a hierarchy of goals, where each higher level goal builds upon the one preceding it. The initial process involves structuring, or engineering, curriculum lessons in accordance with the results of an explicit, detailed cognitive task analysis (Kieras, 1988). Once the instructional material is cognitively structured, additional processes such as error diagnosis and adaptive lesson frame sequencing can be implemented.

Recent research employing Naval personnel has clearly demonstrated the power of this cognitive learning approach in an applied training environment. This methodology has been shown to enhance the instructional capabilities, and therefore the effectiveness, of Navy tactical console embedded training lessons. When this technique was applied to tactical console operation, a significant improvement in learning resulted (Williams, Reynolds, Carolan, Anglin, & Shrestha, 1989; Williams, Reynolds, & Carolan, 1989; and Carolan, Williams, & Moskal, 1992). The primary goal of the present research effort was to determine whether these earlier training benefits could be replicated within the Aegis weapon system Computer-Aided Submode Training (CAST) lessons.

To help operators learn the Aegis weapons system, each console was designed with full embedded training capability. The CAST system was designed as a means of creating and presenting training lessons for each operational submode of the Aegis console. Lessons that have been created are stored on magnetic tapes. When a training session is conducted, the chosen lesson is loaded from tape and presented at the console. CAST lessons are created separately using a CAST authoring program called Lesson Generation (LGEN). Each lesson focuses on specific training objectives for a particular Aegis submode. Within a lesson, trainees can view objectives in any order, and they can backup to review previously presented material. After completing the lesson, students must complete a multiple-choice test on the factual knowledge and an advanced lesson testing the practical application of the knowledge. The advanced lesson presents a series of scenarios to the

trainee, who must perform appropriate procedures to complete the specified task. Depending on lesson performance, trainees advance to new lessons or they can review.

The Electronic Warfare Supervisor (EWS) Submode lesson was selected for use in the evaluation because it was complex enough to thoroughly test the methodology, and it was a lesson which the trainees involved in the experiment would not encounter in the course of their normal training, reducing the likelihood that they would have learned the lesson beforehand. With the original lesson selected, a systematic cognitive task analysis (Kieras, 1987a and 1987b; Williams, Reynolds, and Carolan, 1990) was performed on this lesson, which resulted in a knowledge base consisting of a network of production rules. This knowledge base served as the model of the material to be learned and as the basis for creating the instructional exercises.

The cognitive analysis methodology shares many of the principles and processes of Kieras' (1988) cognitive complexity analysis which is based upon the Goals, Operators, Methods, and Selection Rules, or GOMS model, of Card, Moran and Newell (1983). To perform a cognitive task analysis on the EWS lesson, first a hierarchy of task goals was created. Then the following tasks were completed in the order listed: specific job goals were identified within the lesson, the types of tasks that can be performed on the device which directly relate to the job goals were determined, and the particular tasks to be performed to attain those goals were specified.

Once the job goals and task goals were identified, the methods which made up the task procedures were detailed. Each method specified a goal or subgoal to be accomplished, and the sequence of steps to be executed and conditions to be met, in order to accomplish the associated task goal. Each step of a method consists of an operator or action which is executed. Operators can be perceptual, such as *observing the location of a symbol*; actual, such as *pressing a button*; or cognitive, such as *making a decision*, or *storing or retrieving information from memory*.

The result of this analysis was the detailed specification of all of the knowledge needed to complete tasks associated with console operations required of the EWS. Figure 1 illustrates a subset of the knowledge specification which was produced by the cognitive structuring process. Based on this hierarchical production system model, instructional frames were developed. Each individual rule or declarative fact in the lesson, as well as each rule that combines relevant facts and/or lower level rules, was composed into an individual exercise consisting of a frame or set of frames. In working through the frames, the student learns all the declarative facts and how these facts are interrelated. Each exercise frame created with this methodology is explicitly linked to the conditions, actions, or other rules that make up a production. This methodology is consistent with the instructional systems design principles discussed in the CAST style guide, but provides for a more specific design process. This procedure is explicitly detailed in Williams, Reynolds, Carolan, Anglin, & Shrestha, 1989.

Four primary dependent variables (DVs) were employed during this investigation, in an effort to obtain measures of learning related to performance, recognition, and recall. They were: 1) performance test errors (automatically computed at the console), 2) performance test completion time (automatically computed at the console), 3) posttest declarative knowledge score (percent correct out of 100 on the recognition questions of the posttest), 4) posttest procedural knowledge score (percent correct out of 100 on the posttest recall questions). The hypotheses for this research were as follows:

- 1) Subjects receiving the cognitively structured lesson will perform significantly better than subjects receiving the original lesson (DV 1).
- 2) Subjects receiving the cognitively structured lesson will require significantly less time to complete the performance test than subjects receiving the original lesson (DV 2).

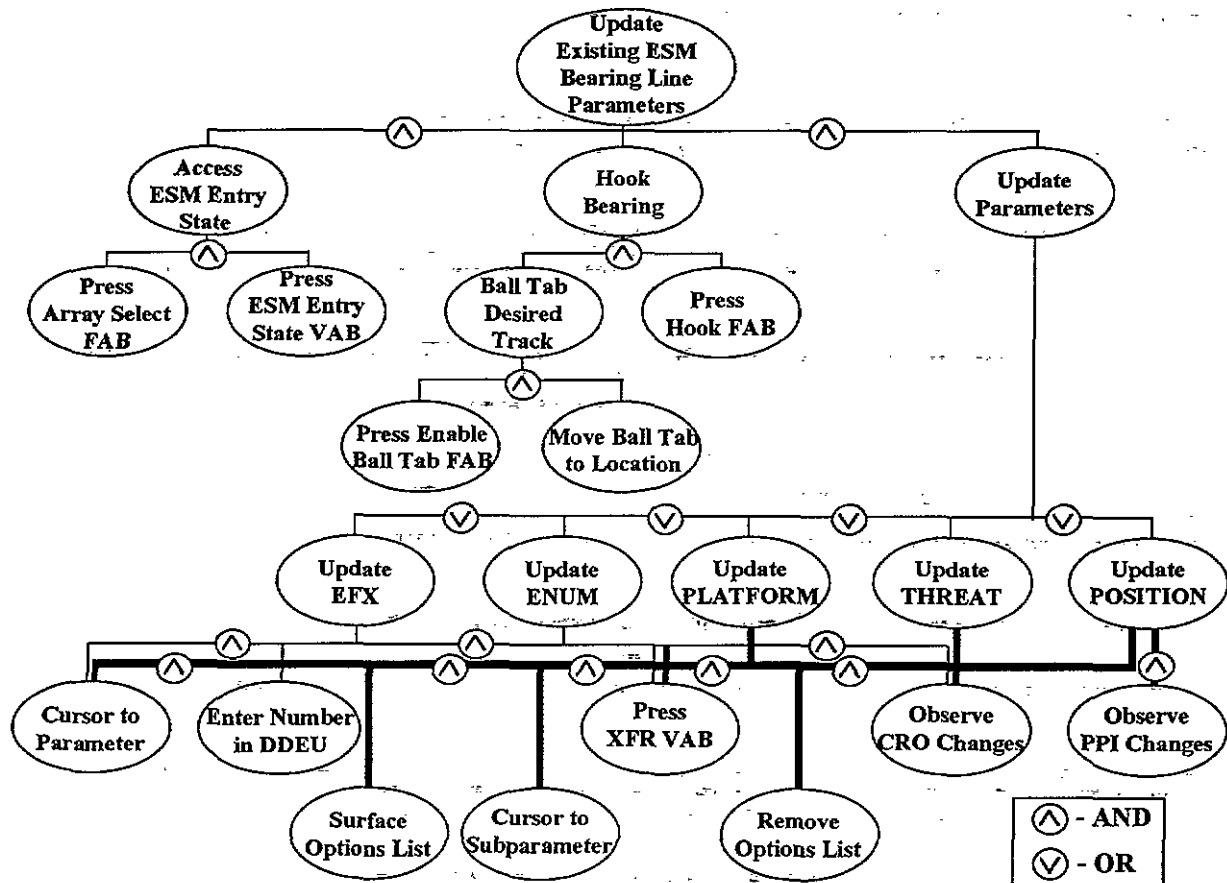


Figure 1. Task-goal hierarchy for the lesson procedure to update an EWS bearing.

- 3) Subjects receiving the cognitively structured lesson will remember more procedural knowledge, but not more declarative knowledge, than subjects in the original lesson condition (DVs 3-4). However, because Aegis CAST lessons are well designed according to instructional systems design principles, the benefit was expected to be less strong than with more typical Navy instruction.

EXPERIMENTAL DESIGN

This research consisted of a standard posttest-only control group design with two factors. The first condition served as the control group, in which subjects received the original lesson, which was a subset of an actual EWS Submode lesson. Subjects in the second condition received the cognitively structured lesson, based on the hierarchical production system

model developed during the cognitive task analysis. The performance test was created by extracting those scenarios in the advanced EWS lesson which directly correlated with the selected objectives taught in the modified original lesson.

Subjects

Twenty-four fire controlmen participated as trainees in this research. They ranged in age from 19 to 30 with a mean of 22.6 years. Their enlisted ratings ranged from E-4 to E-7 with the vast majority being E-4. None of the trainees had prior experience with the EWS Submode CAST lesson, and few had any prior experience operating Aegis CAST lessons or the actual console in one of its operational submodes. Two trainees were eliminated because of equipment failures.

Equipment

The lessons were developed using the Lesson Generation (LGEN) program operating under the VAX/VMS operating system, using the MEGATEK WAND graphics support software. The lessons were presented on Computer Science Corporation (CSC) 451-V9 console emulators, which were controlled by the CAST Lesson Control Program (LCP) residing on a single-bay UYK-7 mainframe computer.

Procedure

The experimental evaluation was conducted in one of the Aegis Training Center's (ATC) Command Information Center mock-up laboratories. The trainee scheduling was done by Navy ATC personnel so that the class schedules of the fire control students were minimally impacted. Prior to the experiment, subjects were asked to provide background information regarding their rank and rating, age, their prior experience on Aegis consoles, CAST lessons, and specifically, the EWS CAST lesson. Subjects were then given general information about the lesson and consoles. They were told that they would spend 45 minutes working on the lesson, and that if they finished before the allotted time, the lesson would automatically restart at the beginning. Subjects were told to continue working on the lesson until the experimenter told them to stop, and they were encouraged to do their best.

Trainees were given an equal amount of time to complete the assigned lesson because pilot research showed that the cognitively structured lesson required more time to complete than the original lesson, and the researchers felt that controlling practice time was crucial. Because each subject was assigned for only one hour, 45 minutes was determined to be the maximum time that could be spent on the lesson and still complete the posttest.

Trainees were randomly assigned to either the original or cognitively structured lesson condition. Within each lesson, subjects had the capability to review any objective and to backpage to review previously displayed frames. Upon completion of the 45 minute training session, subjects were given the advanced lesson which served as the

performance test, followed by the written posttest. Each trainee's performance score (number correct out of 20 items) and time to complete the test were automatically recorded by the computer.

RESULTS

The means, standard deviations, and ranges for each of the four dependent measures across experimental conditions are displayed in Table 1. A qualitative inspection indicates that the data support the hypotheses, as the means obtained in the cognitively structured lesson condition are superior to those obtained in the original lesson condition. The average improvement of the cognitively structured lesson compared to the original lesson, over the four dependent measures is 47 percent.

The goal of the first two analyses was to assess the effect that lesson structure had on the ability to learn and perform procedural tasks associated with the EWS rating. Separate analyses were conducted on the performance test procedures completed and performance test completion time dependent measures. A one-tailed, independent groups t-test was conducted to assess both measures. Both t-tests proved significant ($t(20) = -3.03$, $p < .01$ and $t(20) = 1.90$, $p < .05$, for the performance test and completion time measures, respectively). An assessment of the strength of the treatment effects, or omega squared (w^2) was computed for both dependent measures. The omega squared was .27 for the performance test and .11 for the completion time. Cohen (1977) believes that a large treatment effect in social science research is one with $w^2 > .15$, and a moderate effect is one between .06 and .15. Therefore, our effects appeared to be fairly large.

Thus, on the performance related dependent measures, while controlling for practice time, the trainees receiving the cognitively structured lesson significantly outperformed trainees in the original lesson condition, as predicted. Therefore, the first two hypotheses were confirmed; that is, trainee performance in the cognitively structured lesson condition was significantly better than performance obtained in the original lesson condition.

Table 1. Means, standard deviations, and ranges for each DV across treatment conditions for Experiment Two (N=11 per condition).

Dependent Measures	Condition	
	Original Lesson	Cognitively Structured
Performance test procedures completed (out of 20)	Mean: 10.6 S.D.: 2.8 Range: 7-14	Mean: 13.6 S.D.: 2.5 Range: 10-17
Performance test completion time (minutes)	Mean: 7.0 S.D.: 2.0 Range: 3-10	Mean: 5.5 S.D.: 1.5 Range: 4-8
Posttest declarative knowledge (percent correct)	Mean: 53.5 S.D.: 17.0 Range: 31-88	Mean: 63.8 S.D.: 19.2 Range: 25-94
Posttest procedural knowledge (percent correct)	Mean: 22.0 S.D.: 14.8 Range: 0-45	Mean: 47.4 S.D.: 16.6 Range: 11-67

The multiple-choice questions on the posttest are assumed to be a measure of the trainee's ability to recognize the correct, factual information that was presented during the EWS lesson. The mean posttest score was 59% correct overall (9.4 correct out of 16). Subjects who received the cognitively structured lesson remembered more declarative knowledge than subjects in the original condition (see Table 1). However, the t-test performed on this DV was not significant ($t(20) = -1.34, p < .10$), which corroborates previous research and our hypothesis.

The recall portion of the posttest was intended to assess each subject's ability to recall the specific procedures required to achieve a particular task goal within the EWS lesson. The average number of procedures correctly generated on the posttest, over all subjects, was 35%. Trainees in the original lesson group recalled 22% of the procedures while trainees in the cognitively structured group recalled 47.4% (see Table 1). The t-test performed on this DV was highly significant ($t(20) = -3.78, p < .001$). The omega squared was equal to .38. Thus, as hypothesized, subjects who were in the cognitively structured lesson condition remembered more procedural knowledge on the posttest than did those who were in the original lesson.

DISCUSSION

The results support our contention that procedural knowledge and skills can be learned more effectively when structured according to the cognitive analysis methodology (e.g., Kieras, 1988; Williams, Reynolds, Carolan, Anglin, & Shrestha, 1989). Students training on the cognitively structured lesson performed better than students who received the original lesson.

Examining these data in terms of the number of subjects who reached the 80% correct criterion used by the Aegis Training Center for passing CAST lessons reveals that more of the subjects receiving the cognitively structured lesson reached criterion on the performance test and declarative knowledge section of the posttest than those receiving the original lesson (36% to 0% on the performance test and 18% to 9% on declarative knowledge). On the procedural aspect of the posttest, no one reached criterion, although eight subjects (73%) in the cognitively structured condition remembered over 50 percent of the procedures, in contrast to no one who received the original lesson.

As with our previous research (e.g., Carolan, Williams, & Moskal, 1992), the present results can be interpreted within the context of cognitive science research that makes a distinction between procedural and declarative knowledge representations. It is believed that knowledge is first encoded as facts, but the learner may not use this knowledge to carry out

procedures. Thus, to learn procedural knowledge for a particular task or setting requires that the knowledge be presented in its proper procedural context based on appropriate *individual rules and the relationships among them.*

Carolan, Williams, and Moskal (1992) describe in detail how to cognitively structure training materials. Suffice it to say here that this methodology provides precise direction to design and present material that should make procedural learning highly efficient. This methodology is to be used in addition to the *standard instructional systems design process.* Cognitive science research has shown that presenting instruction in which the specific factual knowledge, procedural rules, and the relationships among them are explicitly observable will significantly enhance learning. Structuring these lesson components in this way provides the means by which they are integrated to promote learning. Enabling trainees to combine factual knowledge with knowledge about performing associated procedures is accomplished through structured practice elements and proper feedback, which ensures that trainees know the procedures that are required and that they have properly interpreted the instructions.

Our findings confirm results obtained on similar research that we conducted for the Navy's Lesson-Translation (L-TRAN) lessons using Navy Tactical Data System (NTDS) consoles (Carolan, Williams, & Moskal, 1992). The present results demonstrate that the cognitive structuring methodology is effective in enhancing learning, even for embedded training lessons like the Aegis CAST system, which should already be efficient because they closely follow instructional systems design principles.

By structuring the lessons based on knowledge and rules that are related in an optimal manner, the first step in creating an intelligent tutoring system (ITS) that can adaptively sequence instruction has been accomplished. Examining the potential training effectiveness of an ITS in the CAST environment is recommended as the next logical step to further evaluating this cognitive structuring approach within the Navy's embedded training research and development

program. This approach could be especially beneficial in this time of reduced budgets.

The cognitive structuring approach has resulted in significant learning enhancements in a variety of environments, and with trainees ranging from novices to instructors. Thus, we believe that this methodology is effective and it can be valuable for developing effective embedded training instruction. However, it does not come without costs. Foremost is the fact that implementing this methodology to restructure existing lessons is very labor intensive and time consuming. The lesson developers must become extremely well acquainted with the lesson content in order to make the proper modifications, and this takes significant time. Second, cognitively structured lessons are often longer than standard lessons, which means that more text and practice will be required. This increase may affect the available memory of the embedded training computer system, and trainees will be required to spend more time on a lesson (though they should require less remediation because more trainees will reach criterion performance quicker). However, if the lessons are created as part of an intelligent tutoring system with exercise sequencing adapted to student strengths and weaknesses, then the average lesson time could be reduced. Using an ITS should allow better students to advance through the lesson more quickly, because they would receive a shorter path with less remediation required.

The user of this approach (the organization conducting the training) must determine if the anticipated training gain is worth the additional costs and constraints. However, when initially designing procedural-based embedded training, the authors recommend developing lessons using this cognitive structuring methodology in conjunction with the standard instructional systems design approach. The costs involved with implementing the cognitive approach initially should not be significantly higher than through the traditional method, because lesson developers must be highly knowledgeable on the instructional content with all design approaches. In fact, this methodology may actually help designers create lessons more efficiently because it requires the information to be highly structured. Moreover, written user

documentation can often be created directly from the structuring process (e.g., Kieras, 1988).

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