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22a. NAME OF RESPONSIBLE INDIVIDUAL Paula J. Konoske		22b. TELEPHONE (Include Area Code) (619) 225-2191	22c. OFFICE SYMBOL Code 42

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COGNITIVE FACTORS IN LEARNING AND RETENTION OF PROCEDURAL TASKS

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**COGNITIVE FACTORS IN LEARNING AND
RETENTION OF PROCEDURAL TASKS**

Paula J. Konoske
John A. Ellis

Reviewed by
E. G. Aiken

Approved by
J. S. McMichael

Released by
B. E. Bacon
Captain, U.S. Navy
Commanding Officer

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Navy Personnel Research and Development Center
San Diego, California 92152-6800

FOREWORD

This effort was conducted under project ZR000-01-000.027 (Cognitive Factors in Learning and Retention). The purpose of this project was to develop a taxonomy of supplemental explanations to facilitate learning, performance, and retention of different types of procedural tasks and to examine the effects of presenting qualitative explanations on learning and retention of an assembly procedural task.

Appreciation is expressed to the students from San Diego State University and enlisted personnel from the Navy Personnel Research and Development Center and the Service School Command, Naval Training Center, San Diego, who participated in the studies.

Results of the research are intended for use by instructional designers within the Naval Education and Training Command.

B. E. BACON
Captain, U.S. Navy
Commanding Officer

J. W. TWEEDDALE
Technical Director

SUMMARY

Problem

Recent surveys have found that most tasks performed in the military are procedural tasks and that procedural tasks are the most important and necessary type of task for Navy mission readiness. Procedural tasks consist of an ordered sequence of steps or operations performed on a single object or in a specific situation to accomplish a goal. They involve few decisions and are generally performed the same way each time. Procedural tasks vary in (1) the amount of planning they require to accomplish, (2) the number of steps and subprocedures they require to accomplish, (3) the amount of cueing built into the task, (4) the number of decision points, (5) whether or not the order of the steps can vary, and (6) whether the goals of the task are internal or external to the task, system, or situation (e.g., operation vs. maintenance). Military personnel in technical ratings must maintain high levels of procedural skill and knowledge in order to be able to perform their jobs successfully. Unfortunately, procedural tasks are frequently not well retained.

One potential solution to the retention problem is to use qualitative explanations, elaborated instructions, and analogies to enable learners to build mental models or representations of systems and tasks which in turn facilitate learning, performance, and retention.

Objectives

The objectives of this research were to (1) develop a taxonomy of qualitative explanations for teaching procedural tasks and (2) test the effects of qualitative explanations on learning, initial performance, and retention of an assembly procedural task.

Approach

The approach of this research was to: (1) review the literature involving types of qualitative explanations and analogies and their effects on the learning and retention of procedural tasks, (2) develop an operationally defined taxonomy of the types of qualitative explanations and the kinds of information each qualitative explanation provides, (3) identify and operationally define several different types of procedural tasks and the kinds of information needed to perform the task correctly, (4) empirically examine the effects of various types of explanations on learning and retention of a procedural task, and (5) develop prescriptive guidelines for determining what types of explanations can be applied to assembly procedural tasks.

The three experiments used a two-factor mixed analysis of variance design with three levels of the between-subjects independent variable, qualitative explanations. The subjects (college undergraduates in Experiment 2 and Navy enlisted personnel in Experiments 1 and 3) were assigned to a linear/structural instruction group, a functional instruction group, or picture-only group. Immediate versus delayed performance testing was the within-subjects variable. Subjects were scored on speed and accuracy of constructing a model crane.

Results and Discussion

Three types of qualitative explanations were identified for specific types of procedural tasks and a taxonomy was developed.

In Experiments 1 and 2, the subjects who received functional qualitative instructions were better at assembling the model initially and after a 1-month retention interval than the subjects who received linear/structural qualitative explanations. However, Experiment 3 showed no advantage for the functional qualitative explanations over the linear/structural explanations or picture-only (control) group. This lack of a real performance difference could indicate a ceiling effect. On an experience questionnaire, the Navy subjects in Experiment 3 reported having more mechanical experience than did the undergraduate subjects in Experiment 2.

Conclusion

The less-experienced college students appeared to benefit more from the qualitative functional instructions than did the experienced Navy subjects, perhaps because the Navy subjects already had enough mechanical experience to make the functional explanations redundant.

Future Directions

Instructional designers should consider the interactions between the learner's knowledge structures, the structure of the information content, and the structure of the task when developing instruction. Instructional developers should consider the tradeoffs in training time and performance for the various types of explanations when designing instruction.

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INTRODUCTION

Problem

Recent surveys¹ have found that military personnel perform mostly procedural tasks (Tarr, 1986) and that this type of task is most important and necessary for Navy mission readiness (Campbell, O'Conner, & Peterson, 1976).

Procedural tasks consist of an ordered sequence of steps or operations performed on a single object or in a specific situation to accomplish a goal. They involve few decisions and are generally performed the same way each time. Procedural tasks vary in (1) the amount of required planning, (2) the number of steps, (3) the amount of built-in cueing, (4) the number of decision points or branches, (5) whether or not the order of the steps can vary, and (6) if the goals of the task are internal or external to the task, system, or situation. The goal of an operator task is external to the system or situation, while the goal of a maintenance task is internal to the task, system, or situation. This research did not consider tasks involving many decision points and branches (e.g., complex problem solving or troubleshooting) to be procedural tasks. However, tasks with few decision points (e.g., repair tasks involving a small number of known possible faults) are considered procedural tasks.

Military personnel in technical ratings must maintain high levels of procedural skills and knowledge in order to be able to perform their jobs. Unfortunately, procedural skills are frequently not well retained (Ellis, 1980; Hagman & Rose, 1983; Hurlock & Montague, 1982; Naylor & Briggs, 1961; Schendel, Shields, & Katz, 1978; Vineberg, 1975). A possible solution to this retention problem is to develop methods for designing instruction that make procedural skills more resistant to forgetting, which is the focus of this effort.

Before proceeding, it is important to note how the definition of a procedural task just given relates to the distinction in the cognitive literature between declarative knowledge and procedural knowledge. Declarative knowledge is knowledge about something (sometimes called "knowledge of"). It is "explicit" in that it is encoded directly. Procedural knowledge is knowledge about how to do something (called "knowledge how"). It is "implicit" in that the procedures have to be executed in order to get the information (Rumelhart & Norman, 1983).

Anderson (1981) proposed a three-stage process of skill acquisition. In the first stage, learners receive instruction and information about a skill. Next, they encode the instruction as a set of facts about a skill (declarative knowledge). Finally with practice, they convert the declarative knowledge into procedural knowledge that can be applied directly. While developing the computer-based Minnesota Adaptive Instructional System, Tennyson, Christensen, and Park (1983) also suggested that learning should be viewed as a range of cognitive processes. This range begins with the acquisition of concrete (skill) knowledge, transitions to the acquisition of conceptual knowledge and skills, and ends with acquisition of the ability to generate new knowledge. This paper examines the declarative phase of procedural skill acquisition and the next stage of converting the factual knowledge into a procedural form, but not how learners acquire the ability to generate new knowledge.

¹Prepublication findings of analysis of curriculum of Navy schools received from D. Van Kekerix (1983).

Objectives

The objectives of this research were to (1) develop a taxonomy of qualitative explanations for teaching procedural tasks and (2) test the effects of qualitative explanations on learning, initial performance, and retention of an assembly procedural task.

Background

Most instruction for procedural tasks in technical training has a linear sequence, uses behavioral terms, and can be described as "lean." Procedural tasks are most often organized and taught as a linear sequence of steps with a single top-level goal. The instruction usually contains the steps or "what" to do, but typically does not contain supplemental qualitative explanation about the logic or rationale underlying the actions to be performed. For example, Smith and Reigeluth (1982) found that instruction in many Navy courses, regardless of the complexity of the task, consisted of an exhaustive, detailed, linear presentation. Instruction presented this way is difficult to retain (Wetzel, Konoske, & Montague, 1983).

The Systems Approach to Instructional Development

During the mid-1950s, training researchers began developing systematic techniques for designing and developing more job-relevant and efficient training. The methods were adapted from those used in operations research and systems engineering for the development of weapon systems (Churchman, 1968). The instruction systems development (ISD) procedures evolved from a conviction that the systems analysis approach, coupled with a behavioral view of learning and instruction, could simplify the complex task of developing programs of instruction. All of the over 100 methods developed (Montemerlo & Tennyson, 1976) contain prescriptive guidelines for (1) analyzing jobs to determine training objectives, (2) developing tests to assess whether trainees are progressing toward objectives, (3) designing and developing instruction, and (4) implementing and evaluating the training program. Such procedures help training experts determine what to do next, but do not supplant the intelligence or knowledge needed to carry on the activity. The version of these procedures currently used by the armed services is the ISD (Branson, Rayner, Cox, Furman, King, & Hannum, 1975; Chief of Naval Technical Training, 1981).

Behavioral psychology influenced ISD in several ways. One way was to identify basic bits of observable performance (Criss, 1983; Montague & Wulfbeck, 1984), which led to a task analysis method that analyzes complicated performance into a series of observable simpler subperformances. In general, ISD tends to identify and teach observable step-by-step performances rather than to analyze the cognitive processes necessary for whole task performance.

Task analysis in industry and in most technical training generally follows the same systems approach, which relies heavily on behavioral psychology. After tasks are analyzed into observable components, they are taught using the laws of learning and instruction derived from operant conditioning (e.g., Taber, Glaser, & Schaefer, 1965). Instructional strategies include sequencing instruction step by step, allowing students to proceed at their own pace, providing frequent reinforcement and diagnostic feedback for responding, to name a few. Montague and Wulfbeck (1984) argue that the lack of attention in ISD to performance context, content structure, conceptual interrelationships, the role of metaphor and analogy in learning and memory, prior knowledge of the student, and the interaction of the entry level behavior with the structure of the content and the

performance context lead to inadequate instruction. Criss (1983) supports this criticism and states that ISD has not succeeded in making training job-relevant, efficient, or cost effective and that "the underlying behavioral model omits cognitive framework, omits important content, and is only a partial system approach" (p. 104). He points out that the primary objective of ISD is to simplify instruction to the level of the student. ISD tends to view the presence of detail and redundancy skeptically as just adding information rather than "making a conscious choice about what information to add" (p. 105).

In the past, procedures have either been taught by rote and practiced until followed flawlessly or they have been taught as magically emerging from abstract engineering theory. Both of these positions have obvious shortcomings. Rote learning of procedures might seem easy and cost effective--certainly easier than theory--but procedures learned by rote are inherently brittle. They must be recalled accurately and thus cannot utilize the reconstructive problem-solving capabilities of the human memory system that enable fragments of partially remembered knowledge to be intelligently joined to form a coherent memory of the desired procedure.

Alternatives to Lean Instruction

Montague and Wulfeck (1984) argue that the current ISD methodology should be modified. They suggest that what needs to be done "is to describe task conditions and performance requirements in sufficient detail for adequate mental representation, and to contrive appropriate forms of instructional representation to promote effective learning and understanding" (p. 14). This arrangement, they suggest, would allow students to develop appropriate mental representations of both the task/system/situation and the content to be learned. With such presentations, students can learn to operate a system or device, learn its principles of operation, exercise required vocabulary and procedures, correct errors, and so forth. Building adequate mental representations using qualitative instructions should allow frequent and rapid practice of procedures to be learned, actively diagnose reasons for performance failure, and provide corrective feedback for errors to eliminate any underlying misconceptions. In order to accomplish this, the representation needs to show the changes resulting from certain actions by the student. Montague and Wulfeck suggest that, as a result of focusing instructional design consideration on representations of the system or device with which the students will be working, learning situations are likely to be more effective.

Bruner (1964) in discussing the elements of instruction also talked of analysis, structuring and sequencing the materials, and providing feedback to the students. However, he emphasized the importance of the structure and form of the knowledge, the (mental) representation of the student's knowledge, and the influence the representation has on the student's performance. This view has been expanded and now is an important part of cognitive science (Norman, 1980).

One attempt to focus design considerations on work or task representations is presented by Riesbeck and Hutchins (1982). They suggest that, when designing instruction for procedural tasks, it is important to specify the motivation and logic underlying the actions (subprocedures) to be done and to provide the student with "why" something is done now rather than later. The goals of the procedure and subprocedures should be explicit and relate the actions in the procedures with the intentions of the problem solver.

Mental Models

The response to the obvious shortcomings of learning procedural skills by rote has been to teach theory, usually a very simplified version of the theory that the engineers used to design the system. But designing the system requires fundamentally different kinds of knowledge and skills than does installing, operating, and maintaining it. Therefore, it is important to determine when and how much theory should be presented when learning specific types of procedural tasks because adding theory or qualitative explanations to instruction increases training time and, therefore, costs. However, adding theory may enhance learning and retention because explanations (including analogies) enable learners to build mental models or mental representations of new tasks from their existing knowledge structures (Greeno, 1982). Mental models have been demonstrated to facilitate learning, performance, and retention of both procedural tasks and complex rule- and principle-based tasks (Gentner, 1980; 1981; Kieras, 1981; Smith & Goodman, 1982; Sturgis, Ellis, & Wulfeck, 1981; Tourangeau & Sternberg, 1982). Mental models of systems are more or less simplified representations of how the systems work. Models are more qualitative than quantitative. They describe the system in terms of the structure and the kinds of interactions that occur in the system rather than computing exact values. For example, when people think about the braking system on their car, they do so in terms of force on the pedal being translated into force on the brake shoes. Rarely do they think of applying the brakes in terms of exact measurements of hydraulic fluid pressure and time or distance needed to stop the car.

Recent lines of research in cognitive psychology have examined various mental representations and how they affect learning, memory, and performance. For example, considerable research has revealed the important role of organization and/or schemata in learning, reading, and comprehension. Results have demonstrated that the cognitive structures of the learner interact with the structure of the material to be learned (e.g., Chiesi, Spilich, & Voss, 1979; Rumelhart & Ortony, 1977; Schank, 1980; Schank & Abelson, 1977).

The literature on cognitive analysis indicates that the design of the instructional presentation must be concerned with the match between what the learner already understands and the structure of the task/material to be learned. This is needed to help students apprehend the material and probably will depend on the students' familiarity with the representational form. Since familiarity of the representational form is important, it seems likely that the representation appropriate at early stages in learning might have to be quite different from that appropriate at later stages.

Research on problem solving also reveals the importance of representation and structure. The quality of a person's representation of the problem determines the adequacy of the solution (e.g., Greeno, 1977; Hayes & Simon, 1976; Simon & Simon, 1978). Novices and experts differ in aspects of their approaches to problem solution, primarily in the level of strategic knowledge applied (e.g., Chi, Feltovich, & Glaser, 1981). Some of this expert strategic knowledge can be used to structure procedures to guide novices in problem solutions (Reif, 1979; Reif & Heller, 1982) and has produced substantial improvements in performance (Heller & Reif, 1982). Thus, problem solving research also seems likely to contribute to improving instructional techniques. These lines of cognitive research suggest the importance of an adequate mental representation for learning, performance, and retention.

Next, we will review the types of qualitative explanations that have been used to help learners build representations and discuss studies that investigated the effects of qualitative explanations on learning, performance, and retention.

Unfortunately very little work has been done on procedural tasks and the discussions and definitions of qualitative explanations, analogies, and related areas differ (Bieger & Glock, 1982; Smith & Goodman, 1982; Stevens & Steinberg, 1981). For example, Stevens and Steinberg (1981) examined textual explanations directed at providing students with an understanding of how complex physical systems operate. They developed a taxonomy of the following types of explanations: behavioral, physical-causal, state-attribute, component, and geometric. In general, explanations derived from the physical systems can provide a linear sequence of facts, the static structure of the system, the functional changes of attributes, information for determining interactions, or quantitative information.

Bieger and Glock (1982), on the other hand, developed a taxonomy of the kinds of information used in picture-text instruction for two procedural assembly tasks. The kinds of information included information about objects, actions, the structure of materials, the general outcome of following certain procedures, and cause and effect relationships.

We adopted the types of qualitative explanations identified by Smith and Goodman (1982) and by Stevens and Steinberg (1981)--linear, structural, and functional. These types incorporate the kinds of explanations described by others and are also relatively easy to define operationally. Linear explanations provide the student with information about what to do with the system or in the situation; structural explanations, information about how or why the system or situation is constructed; and functional explanations, information about how or why the system/situation works.

Because procedural tasks consist of an ordered series of steps, structural and functional explanations always include linear information. Structural and functional explanations may be presented independently or in combination. Explanations can also be organized hierarchically. All types of explanations can explain the system, situation, device, or task directly or indirectly using analogies. Analogies, which present qualitative explanations indirectly, can be linear, structural, or functional.

Next, we will define the three types of explanations operationally and review the research investigating the effects of presenting supplemental information on learning and retention of tasks. Table 1 summarizes the research reviewed in the order discussed below. None of the studies tested the learner comprehension of the supplemental information.

Table 1

Summary of the Literature of the Effects of Qualitative Explanations on Learning and Retention

Explanation Type/Author	Task	Outcome
<u>Linear</u>		
Hagman & Rose (1983)	Don a gas mask. Assemble/disassemble M-60 machine gun. Test alternator electrical output. Format/type military correspondence. Report enemy information. Load & fire M203 grenade launcher. Perform CPR.	Performance degrades as number of steps increases and amount of cueing decreases.
Dixon (1982)	Operate unfamiliar electronic device.	Reading faster when action information presented first and condition second.
Spoehr, Morris, & Smith (1983)	Operate unfamiliar device.	Faster comprehension when information is in order of antecedent, action, consequence.
<u>Structural</u>		
Smith & Goodman (1982)	Assemble electric circuit.	Steps read faster, performed more accurately, and recalled better with functional information than with structural and linear.
Baggett (1983a, 1983b)	Assemble model.	Identified "typical" conceptualization.
Bieger (1982)	Construct fabric task. Assemble model loading cart.	Pictorial illustrations more effective than text only.
Stone & Glock (1981)	Assemble model loading cart.	Text plus illustrations produced most accurate performance.
Loman & Mayer (1983)	Expository prose. Solve problems about mathematics.	"Signaling" facilitated recall and problem generation.
Greeno, Vesonder, & Majetic (1982)	Solve problems about transmission of sound.	No group differences.
<u>Functional</u>		
Myers, Hansen, Robson, & McCann (1983)	Learn elementary probability concepts.	Explanation facilitated performance on story problems, but not on formula problems.
Kieras & Bovair (1983)	Operate unfamiliar equipment.	Presence of a model facilitated learning and retention.
<u>Analogies</u>		
Gentner (1982)	Provide framework for using analyzer.	Theoretical discussion of domain matching.
Gentner & Gentner (1982)	Answer questions regarding electricity.	Analogies serve as inferential framework.
Riley (1983)	Answer questions about electric circuit function.	Structural analogy not sufficient; need better mapping between tasks and analogies.
Rigney & Lutz (1974)	Solve science problem.	Visual analogies facilitate understanding of invisible processors.
Mayer (1975)	Generate computer program.	Presence of a model facilitated program interpretation, but not program generation.
Hayes & Henk (1983)	Tie a bowline knot.	Pictures better than analogy on immediate recall, but long term retention best for analogy group.

Types of Explanations

Linear

Linear instruction contains a single top-level goal and a sequence of linear steps ("first do this, next do that, etc."), is usually sequentially presented, and includes specific declarative information about the system, device, and steps the task contains. The explanatory material in linear instruction specifies the general goal of the task. If the task is complex--that is, if it contains several subprocedures--the linear instructions for the subprocedures may be structured hierarchically to transmit the goals of the subprocedure. However, hierarchical structuring is not necessary for most tasks. For example, linear instructions for changing a flat tire contain only a single top-level goal (replace the flat tire with a good tire) and the following sequence of linear steps: (1) apply handbrake, (2) get a screwdriver, (3) pry off the hubcap, (4) get a wrench, (5) loosen the bolts that hold the wheel onto the rim, (6) get a jack, (7) place it under the car on the side of the damaged tire, (8) raise the car, (9) and so forth. Martino's (1964) hierarchical presentation for changing a flat tire contains several subprocedures (e.g., removing the wheel, jacking up car). These can be broken out and their goals identified explicitly. These goals can also be presented at the start of the instructional material (e.g., performance objective) or for each subprocedure as the task is executed (Riesbeck & Hutchins, 1982; Smith & Goodman, 1982).

Typically, linear instructions do not explain to the learner how/why the system/situation is structured as it is or how/why the system/situation functions. Linear instructions include only the executable steps and how to perform them. Linear instructions do not address the important relationships between steps, can be learned by rote memorization, and may overload processing ability if the procedure is long and/or complicated and provides no context for retrieval.

Hagman and Rose (1983) studied the retention of procedural motor skills performed in the operational environment. The tasks included donning a gas mask, assembling and disassembling an M-60 machine gun, testing the alternator electrical output, formatting and typing military correspondence (aided and unaided), reporting enemy information, loading and firing the M203 grenade launcher, and performing CPR. Although Hagman and Rose were interested in the effects of varying amount of practice on the learning and retention of procedural tasks, the instructional materials consisted of a linear presentation with a single top-level goal statement. They identified two task characteristics that influence retention: the number of steps required and the presence or absence of sequential cues. In general, they concluded that procedural tasks with few steps and/or with steps that are cued by the equipment or a previous step can be taught by presenting a linear sequence of executable steps. However, complex procedural tasks--tasks with many steps and with steps that are not cued by the equipment or a previous step--may need additional explanations to facilitate learning, performance, and retention.

The way information is presented within steps has also been found to be important. Dixon (1982) measured sentence reading time while subjects followed multistep, linear procedural directions for operating an unfamiliar electronic device. Sentences were read faster when action information (e.g., turn the left knob) came first and condition information (e.g., the alpha meter should read 20) came second. This effect was observed when the condition information was an antecedent or a consequence of the action and when the action was performed immediately or from memory. Dixon concluded that learners organize linear procedural directions for operating devices around the actions to be performed and that they remember condition information only with respect to

particular actions. Besides providing a goal, presenting the action information first provides the information in the order needed. In more complex tasks when branching is possible, condition information may be more important when it specifies which of a variety of possible actions should be performed. In a replication of the Dixon study, Spoehr, Morris, and Smith (1983) found that learners comprehend written instructions for operating an unfamiliar device faster if the information is in the same order as needed to carry out the instruction (antecedent, action, consequence). The advantage of presenting the action information first and the condition information second (Dixon, 1982) affected only reading times and not errors. The usefulness of these findings may be limited to situations in which time is an important performance measure.

Structural

Structural explanations deal with the components of a task, system, or situation and how and/or why they interconnect. They emphasize spatial relations and describe the component structure, component interrelationships, or physical structure of the task, system, or situation. They are static and are often communicated by using schematic diagrams that visually display the component interrelationships.

For procedural tasks that include assembling components to construct a finished product, structural explanations are identical to hierarchically organized linear explanations. For other types of procedural tasks, structural explanations include information about components of the system or situation.

The hypothesis that performance of an assembly task would be better if instructions include higher-level, hierarchically organized, explanatory material than material not hierarchically organized was tested by Smith and Goodman (1982). This type of explanatory material, they reasoned, would provide the learner with both a representation of the task and a rationale for each executable step. Further, they assumed that people try to construct a task representation that relates all the steps. They suggested that constructing a representation to present the learner with additional explanatory material (making it hierarchical) would be easier than confining the representation to steps. To test this, they composed three sets of instructions for assembling an electrical circuit. One contained the typical linear organization; another contained a hierarchical organization of the linear steps (similar to the tire changing example), which Smith and Goodman call a structural explanation. However, for procedural assembly tasks, explanations about the task structure are identical to hierarchically organized linear explanations. The third, called functional, contained a hierarchical organization of the linear steps plus explanatory material that described how the different components of the circuit worked.

Smith and Goodman² presented three major findings of interest:

1. First, subjects read the steps faster with hierarchical/structural and functional instructions than with linear ones. They suggest that hierarchically organized instructions decrease reading time by providing an explanatory schema for the steps. The mechanism they considered was that of preactivation; that is, some steps contain concepts previously mentioned in an explanatory statement and these "preactivated" steps required less processing.

²One essential goal of the research presented herein was to replicate and extend the Smith and Goodman study (1982).

2. Subjects made fewer errors in task execution with hierarchical/structural and functional instructions than with linear ones. They concluded that subjects who received hierarchical/structural and functional explanations developed a representation of the steps that allowed them to use some of this higher level information as constraints on how to execute some of the steps, thereby reducing the incidence of errors. In other words, there is always a potential for vagueness in explanations of procedural steps, and one can reduce this vagueness by bringing in constraining information in the form of additional explanatory material.

3. Subjects receiving functional explanations performed the assembly task best, while subjects receiving linear and hierarchical/structural explanations performed equally poorly. Smith and Goodman suggested that the functional explanatory material was a better guide for performance than its hierarchical/structural counterpart. However, as mentioned previously, the lack of a performance difference for subjects receiving linear and hierarchical/structural explanations could also be attributed to the similarity of these explanations; that is, Smith and Goodman's structural explanation really is just a hierarchically organized linear explanation of the subprocedures of the task.

In other studies illustrations have frequently been used to present structural information about a procedural assembly task (Baggett, 1983a, 1983b). Bieger (1982) using two procedural assembly tasks investigated the effects of including different types of information on task performance. Bieger concluded that including illustrations in assembly instructions facilitates the performance of the procedure because pictures supply operational, contextual, and spatial information.

A related study attempted to determine whether the addition of line drawings equal in information content to text directions would enhance comprehension compared with that produced by either text or line drawings presented alone (Stone & Glock, 1981). They developed procedural directions, in text form and in illustration form, for assembling a model of a loading cart. In this instance, the line drawings constituted a structural explanation, because they provided spatial and component part information. The subjects who received text plus line drawings performed more accurately and made fewer errors in the orientation of parts than did subjects who received either text or illustrations. They concluded that illustrations convey spatial information more effectively than do unillustrated prose instructions. For procedural assembly tasks, illustrations appear to convey structural information effectively.

In two other experiments, Loman and Mayer (1983) found that groups receiving explanations of the structure of relations, summary statements, or goal statements performed better on recall of conceptual information and on generating high quality problem solutions than did groups not receiving the additional explanation. They hypothesized that providing additional qualitative explanations makes the conceptual organization in a passage more obvious to the learner. Although they used expository prose in their two experiments, providing the structural information may also facilitate learning and retention of procedural tasks.

Greeno, Vesonder, and Majetic (1982) investigated whether instruction regarding the detailed structure of sound transmission would enhance students' ability to reason about properties of that process. They designed two instructional units about the transmission of sound. The first focused on amplitude and frequency of sound waves and the temporal properties of sound waves at a single point in space. The second focused on the

mechanism of sound transmission. The instruction was designed to teach the microstructure of the causal system and was structural. The subjects in this study were sixth grade students with limited general knowledge about sound transmission. Two groups of subjects studied the instructional units and another was used as the control group. The performance of the two groups on inferential questions did not differ from that of a control group. The authors concluded that the explanation of the detailed structure of the system did not strengthen acquisition of the concepts. However, they suggested that either the instructional units did not convey the information explicitly or, more likely, the structural qualitative explanation did not support the performance of the task. They speculated that an explanation including dynamics of sound transmission--a functional explanation--could improve acquisition and retention of the principles. This study points to the difficulty of identifying the appropriate type of qualitative explanation.

Functional

Functional explanations involve information about the cause and effect relationships underlying tasks. Functional explanations about systems or some ongoing situation emphasize variations of properties with time and are action oriented. They describe how things happen and why they work as they do; that is, they are dynamic.

The effects of varying the degree of explanation of basic concepts of elementary probability on learning was studied by Myers, Hansen, Robson, and McCann (1983). Three texts were prepared. All contained six formulas, each accompanied by an example as well as definitions and information logically required to solve all problems. The high explanatory text differed from the low explanatory and the standard texts in that it emphasized the logical basis underlying the construction of the formulas, the relations among formulas, and the relations of variables to real-world objects and events. The high explanatory text contained a functional explanation. The standard text did not give real-world examples. On both immediate and delayed (2 days) tests, the subjects who studied the low explanatory and standard texts performed better on the formula than on story problems. However, the subjects who studied the high explanatory text did equally well on both types of problems. Myers et al. concluded that the type of explanation did not improve the learning of formulas, but facilitated the application of what was learned to story problems. These findings suggest that functional explanations may provide greater qualitative understanding than linear explanations.

As part of an investigation of the role of mental models in learning how to operate an unfamiliar piece of equipment (Kieras & Bovair, 1983), subjects learned a procedure for operating a simple control panel device consisting of switches and indicator lights. The goal of the procedure was to get one of the lights to flash. The model group was told that the control panel operated the phasers on the Starship Enterprise. They were given a functional explanation (i.e., how each component was involved in firing the phasers) for each of the switches and lights. The rote group received no supplemental explanations and was required to learn the procedures by rote memorization. Both groups were tested immediately after learning the procedure and one week later for retention of the procedures. The model group learned the procedure faster and, after one week, retained it better and executed it faster.

In the Kieras and Bovair study, having a functional model of the device facilitated learning and retention. They concluded that the additional functional explanation made it possible to infer the procedures for operating the device and that, in learning an operating procedure, the application or relevance of the model to the actual task is more important than the depth of understanding of how the device works.

Analogies

In addition to presenting direct qualitative explanations to enhance learning and retention, research has also investigated the effect of a more indirect instantiation of mental representations on learning and retention. Using an analogy makes new knowledge familiar by relating it to already known, very similar knowledge outside the immediate content area of interest.

A number of studies have investigated the use of analogies as a way of improving learning and retention of complex tasks. It is common instructional practice to introduce a new topic by using an analogy to a familiar domain. The real question is how to choose an appropriate or good analogy. Analogies that elicit erroneous inferences can interfere with learning (Gentner, 1982; Gentner & Gentner, 1982; Riley, 1983). Animated visual analogies have been suggested as important in teaching invisible processes or in understanding complex sequences of events in science (Rigney & Lutz, 1974). An interactive analogy can direct student attention to particular aspects of the process as they occur and convey dynamic changes in events that would otherwise be very difficult to explain (Forbus, 1981).

An analogy may be a set of propositions about the subject matter. An analogy symbolizes the critical, relevant attributes of the processes or concepts being communicated to the learner (Rigney & Lutz, 1974). To be useful or effective, an analogy of this type must be (1) a correct representation of relevant aspects of objects or relations, (2) a representation that learners can recognize or understand, (3) an unambiguous representation, and (4) a representation that provides the basis for straightforward transfer to the task (Arnheim, 1969; Riley, 1981).

Mayer (1975) found that the presentation of an analogy describing the structure of a computer expressed in familiar terms facilitated learning and posttest performance. The analogy provided a linear and structural explanation of the computer, described the computer components as a shopping list, and explained how the components fit together. Subjects who received the analogy performed best on interpretation of programs and on problems requiring looping, while subjects who did not receive the analogy excelled on straightforward generation of programs. This suggests that presenting subjects with an analogous model of the computer will allow them to use prior experiences to organize and understand new information. Mayer concluded that new information is integrated with prior information whenever possible.

Riley (1983), on the other hand, found that the presentation of a structural analogy alone was not sufficient for the conceptual understanding of the functioning of electrical circuits. She concluded that unless students practice using the analogy in the context of the task, the structural understanding will degrade. She argues for a better understanding of the types of qualitative "mapping" between tasks and analogies. This finding also supports the declarative and procedural knowledge distinction made in the Introduction (see p. 1) that factual declarative information is necessary, but not sufficient for acquiring procedural knowledge.

The differential effects of pictorial and verbal illustrations on clarifying written instructions and fostering durability of learning was examined by Hayes and Henk (1983). In their experiment, students receiving instructions that included a linear analogy about how to tie a bowline knot understood the task better and were more successful at

completing the task than were students receiving pictorial illustrations alone. With the instructions available for students to study, a linear analogy (a rabbit racing around a tree. . .) did not affect initial learning. It neither inhibited nor enhanced task performance; nor did the type of pictorial illustrations matter. However, after an interval of 10 days, students who were given instructions containing a linear analogy were more likely to remember how to perform the task accurately.

In conclusion, researchers consistently find that analogical presentations of unfamiliar material are remembered better than literal presentations, partly because of the power of analogies to explain and make the topic meaningful by specifying familiar reference points and the relations between them, but also because analogy comprehension requires encoding that fuses disparate semantic domains and thereby sets up a rich matrix of meaning that is useful for retrieval.

Summary

All effective qualitative explanations include linear instructions. All effective linear instructions should include an explicit single top-level goal. If the task has many steps (that is, if it contains several subprocedures), the linear instructions should include the goal for each subprocedure as the task is executed. Further, the sequence of the individual steps of the procedure should follow an action-first condition-second format. Effective structural instructions should also include spatial and component part information (how/why information) as well as the text, schematics, graphs, and illustrations whenever possible. Effective functional explanations should include information about how/why things work as they do. The cause and effect relationships underlying the task should be presented. Any constraints imposed by the situation should be explicitly stated in terms of how to perform within these constraints.

The next section discusses when and what type of supplemental explanation should be presented for learning procedural tasks. Because procedural tasks differ in a variety of ways, the initial part of this discussion involves identifying the types of procedural tasks.

Types of Procedural Tasks

Procedures typically are performed either with continuous actions or discrete actions. In a continuous procedure, the boundaries between the action segments are difficult to determine. A continuous procedure involves high levels of motor skill and automaticity. Thus, experts perform actions in a more coordinated and highly chunked manner than do novices. A discrete procedure involves low levels of motor skill and little automaticity. The nature of the actions, the divisions between them, and the degree to which they are separable change relatively little when performed by experts or novices.

Four types of procedural tasks are discussed below. Within each type of task, the procedures can be continuous or discrete.

1. Operator tasks. Operator tasks require the performance of a procedure on a system or device to accomplish a goal that is usually external to that system or device. The system or device is used as a tool to achieve that goal and is the means by which the task goal is accomplished. Examples of operator tasks include mowing a lawn and driving a car.

2. Maintenance/Repair/Assembly tasks. Maintenance/repair/assembly tasks require the performance of a procedure to maintain, repair, or assemble a system or device. The goal of maintenance and repair tasks is to perform a specific operation on the system or device. Examples of maintenance and repair tasks include changing the oil in a car and fixing an electric circuit. Assembly tasks require combining parts into a completed product. They are subtasks of maintenance/repair tasks, because most maintenance and repair tasks involve disassembling and reassembling a device or system; for example, building a cabinet, constructing an electrical circuit, or assembling a bike, wheelbarrow, basketball backboard, and ping pong table.

3. Paper-based tasks. Paper-based tasks involve the use of specific formatting procedures for preparing documents or the completing standard forms. Examples of this type of task include filling out tax, social security, or employment forms or writing memos in the correct format.

4. Locating information/objects tasks. Locating information or objects that are available in a repository requires knowledge of the storage system. Examples of this task are using a table of contents, library card catalogue, or dictionary and retrieving a part in a supply center.

Taxonomy of Procedural Tasks and Explanations

As discussed previously, research has shown that procedural skills are frequently not well retained. Several studies found retention of operator tasks to be a function of the degree of logical sequential patterning of the task (Anderson, 1981; Tennyson et al., 1983). If the task is composed of steps without some degree of logical sequence, rapid forgetting occurs. Performance of maintenance/repair/assembly, paper-based, and locating information/objects tasks degrades over time when the instructional materials consist of a linear explanation of the task steps (Hagman & Rose, 1983; Naylor & Briggs, 1961; Smith & Goodman, 1982). When a task contains many steps or subprocedures not cued by the situation or the previous step, a linear presentation often results in difficulty remembering and executing the steps.

The rationale for including qualitative explanations (including analogies) is that the learners are able to build mental models or more concrete representations of the task. Instructions that provide learners with a mental model may facilitate acquisition and retention of new material. A mental representation of this sort may decrease errors in initial learning and enhance long term retention. Mental models have been demonstrated to facilitate learning performance, and retention of complex rule- and principle-based tasks (Gentner, 1980; Kieras, 1981; Sturgis et al., 1981; Tourangeau & Sternberg, 1982). Williams, Hollan, and Stevens (1983) also theorize that structural models are an important basis for recall. Thus, mental models may enhance learning and facilitate retention.

The following discussion concerns how to apply the three types of qualitative explanations to specific types of procedural tasks. When students are taught a procedural task, they are always given a linear explanation. Functional explanations sometimes include structural information because of the nature of the task or situation. Thus, some procedural tasks would require all types of explanations, while others may require only one or two types to facilitate learning and retention. For example, operating the brakes of a car does not require structural knowledge about the brakes but does require the qualitative functional information that your foot pushing on the pedal stops the car. However, repairing the brakes on a car requires knowledge about how the brakes are put

together, as well as the cause and effect functional relationships of the parts. Table 2 shows the types of explanations we hypothesized to facilitate learning and retention for different types of procedural tasks.

Table 2
Type of Procedural Task by Type of Explanation

Type of Procedural Task	Type of Explanation				
	Linear	Structural		Functional	
		How	Why	How	Why
1. Operator	X	X	X	+	+
2. Maintenance					
Repair	X	+	+	+	+
Assembly	X	+	+	+	+
3. Paper-based					
Filling out forms	X	+	--	--	--
Formatting documents	X	+	+	+	--
4. Locating information/objects	X	+	+	+	+

Notes.

1. X Indicates that an explanation can be applied to the procedure.
2. + Indicates that applying an explanation to the procedure should facilitate performance/retention.
3. Explanations can be direct or analogical.

1. Operator tasks. Since operator tasks require the performance of a procedure on a device or system to accomplish an external goal, we hypothesize that functional explanations facilitate learning and retention more than do structural explanations (Kieras & Bovair, 1983). Additional explanations for operator tasks should include information about how/why the steps of the task are related to the particular outcome, but need not include information about the internal structure of the device or system. For example, in order to operate a telephone, callers need to know why their actions result in a particular outcome; that is, dialing the telephone number causes the telephone to ring. Providing student operators with a mental model of how to operate a telephone may facilitate performance. Further, a structural explanation does not facilitate learning and retention because how the parts of the telephone system work and fit together is not required to operate it (Greeno et al., 1982; Riley, 1983; Smith & Goodman, 1982). Functional information is also not essential; however, we hypothesize that knowing what happens in a system when an action is performed will facilitate retention (What does a busy signal indicate?), especially if the system is complicated, because the explanation provides a coherent model of the task.

2. Maintenance tasks. Because doing something to the device/system is the main goal of maintenance--including repair and assembly--tasks, we hypothesized that explanatory material about both the function and the structure of the system will facilitate retention. However, learners can also be taught to perform these tasks correctly with only linear instructions. In addition, as discussed previously, structural information for maintenance/repair/assembly tasks is automatically included in the linear presentation of the task (e.g., changing the oil in a car). For certain maintenance/repair/assembly tasks, this "linear-structural" explanation may be sufficient (Bieger & Glock, 1982; Schorr & Glock, 1983), but learning and retention of more complex tasks will probably require supplemental functional explanations. A simple linear presentation of executable steps does not explain how the steps of the task are related to the functioning of the device or system. However, for certain types of maintenance/repair/assembly tasks, information about structure (why) conveys the same information as functional (how) explanations. It is expected that supplemental explanations will help learners construct a "mental model" of the system or situation, which should decrease errors in initial learning and enhance long term retention (Hayes & Henk, 1983; Loman & Mayer, 1983; Smith & Goodman, 1982).

3. Paper-based tasks. There are two types of paper-based tasks: filling out forms and formatting procedures for preparing documents. Filling out a form is typically a highly cued and linear task. Structural and functional explanations cannot easily be applied to this type of procedure because the form is the structure and there are usually no functional relationships. Thus, paper-based tasks with explicit cueing of each step do not require elaborate explanations; a linear presentation should be sufficient.

Using formatting procedures for preparing documents is also typically highly cued. The formatting guidelines are the structure. However, there may be functional relationships in the sense that certain formats may make documents easier to follow, facilitate editing, and so forth. Further, a structural (why) explanation and a functional (how) explanation would convey the identical qualitative information. Providing learners with this type of functional information could enhance learning and retention.

4. Locating information/objects tasks. The procedural task of locating information/objects requires knowledge of a storage system and how to use it. Storage systems are usually logically structured (e.g., Dewey decimal system). Therefore, it is hypothesized that structural explanations about system design will facilitate learning and retention of this type of task. If the rationale for the storage system organization is functional, then functional explanations would also apply (Kinnucan, 1984).

Analogies are a form of qualitative explanations and can be linear, structural, or functional. The same rationale for applying qualitative explanations to procedural tasks also applies to analogical qualitative explanations.

EXPERIMENTS

General Design

The experimental design for testing the effects of the various types of explanations on learning, performance, and retention of a procedural assembly task is described below. The assembly task was chosen because it exemplifies a discrete procedure, is similar to tasks used in previous research on procedures, and is feasible and describable (Baggett, 1983a, 1983b; Baggett & Ehrenfeucht, 1985; Bieger & Glock, 1982; Crandall & Glock, 1981; Stone & Glock, 1980).

Task

The task was to assemble a working model crane from a Capsela 1000 kit.³ This construction kit is similar to Fisher Technik and Lego kits, is manufactured in Hong Kong, and has 46 different plastic, metal, and rubber parts for a total of 112 pieces. The Capsela system is built around a series of capsules, each having a distinct mechanical or electrical function. The electrical connections are made by plugs and sockets. The parts, each with its own function, can be assembled in a variety of ways to create working motorized models. The object to be built, a model chain drive pulley, consists of 21 different parts and a total of 102 pieces (see Figure 1).

Instructions

1. The structural instruction consisted of a linear/structural explanation with a single top-level goal, a sequence of executable steps, a structural explanation for each step, and a picture of the finished model.
2. The functional instruction consisted of a linear/structural plus functional explanation with a top-level goal, a linear explanation with a sequence of executable steps, a structural explanation for each step, and a functional (how/why) explanation of the steps, and a picture of the finished model.

The reading grade level (Flesch) of the structural instruction was 7.8; and the functional instruction, 7.6. Both are presented in the Appendix. Subjects read the instructions at their own pace.

Dependent Variables

The experimental design was a two-factor mixed analysis of variance. Three levels of the between-subjects independent variable--qualitative explanations--were used. The three explanation groups included: (1) linear/structural explanations only (structural), (2) linear/structural plus functional explanations (functional), and (3) picture only. Immediate and delayed (1 month) performance testing was the within-subjects variable. The following classes of dependent variables were analyzed: (1) individual difference, (2) product, and (3) process.

1. Individual difference measures. The subjects were asked to provide basic demographic data and to rate themselves on how often they had played with model kits, their electronics knowledge, and their manual dexterity. They used a 10-point scale (1 = never or none and 10 = very often or very much).

After completing the questionnaire, all subjects took four paper and pencil subtests of the Armed Services Vocational Aptitude Battery (ASVAB): space perception, electronics information, mechanical comprehension, and automotive information. It was assumed that these areas are related to learning and performing an assembly task; therefore, these measures were used as covariates.

³Identification of specific equipment is for documentation only and does not imply any endorsement.

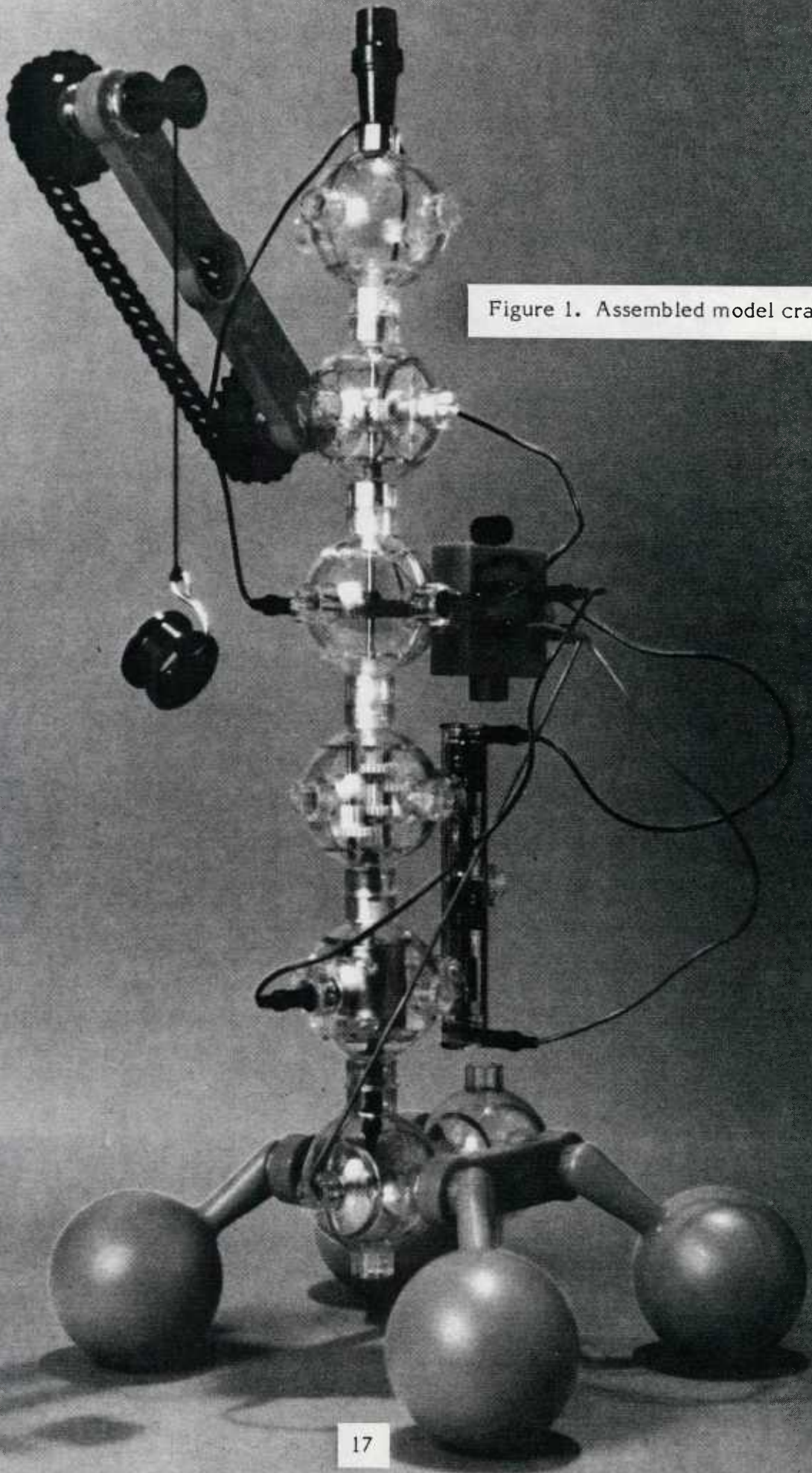


Figure 1. Assembled model crane.

2. Product measures. Outcome measures include the score on an oral part identification test, number of trials (each turn of the ON/OFF switch defined as a trial) to reach criterion of one errorless trial during initial learning (accuracy), scores on a written test of part names and functions (knowledge test), performance test scores, and time measures on reading the instructions and taking the knowledge and performance tests.

3. Process measures. These measures consist of the accuracy of the steps used (i.e., errors or omissions) and the scores on the qualitative test to predict different operations of the system.

Table 3 lists the types of measures and when they were collected.

Table 3
Dependent Measures for Initial and Retention Performance

Dependent Measure	Initial Performance	Retention Performance (1 month)
Individual difference		
Questionnaire	X	--
ASVAB pretests	X	--
Product		
Part identification	X	X
Part name and function (knowledge)	--	X
Performance test	X	X
Speed	X	X
Accuracy	X	X
Score	X	X
Time		
Reading instructions	X	--
Taking knowledge test	X	X
Taking performance test	X	X
Qualitative test	--	X
Process		
Step sequence	X	X
Error types	X	X

Notes.

1. X Indicates when these data were collected.
2. -- Identifies measures not administered.

Hypotheses

Three experiments tested the following hypotheses for initial learning and retention performance of an assembly procedural task:

1. All groups will be able to identify all parts immediately following training, because instructions will require all students to name each part.
2. Total performance test scores for all groups will not differ immediately after training because all learners must make the model crane function. The functional instruction group will require the fewest trials to reach criterion.
3. The functional instruction group will chose the fewest steps and most accurate sequence to reach criterion.
4. The three groups will need differing amounts of time to read the instructions with the functional instruction group needing the most and the picture-only group, the least.
5. The three groups will perform knowledge and performance tests at different speeds with the functional instruction group the fastest.

The following hypotheses were tested for performance after a 1-month interval:

1. The functional instruction group will score the highest on the part identification test. The scores on the part function test will show that the functional instruction group had the best qualitative understanding of the assembly task, followed by the picture-only group, and, last, the structural instruction group.
2. The functional instruction group will receive the highest performance test scores. Further, the functional instruction group will require the fewest trials to complete a working model.
3. The functional instruction group will choose the fewest steps and most accurate sequence to reach criterion.
4. The functional instruction group will be the fastest in completing both the knowledge and performance tests.

In general, the subjects receiving functional instruction were expected to perform and retain the assembly task better than the subjects receiving either structural or picture-only instructions. It was also expected that a relationship will be found among subject background, type of instruction/explanation, and task performance.

The following sections discuss the three experiments. Experiment 1 was a pilot study that investigated procedural aspects of the experimental design and instructions. Experiment 2 incorporated the methodological and procedural changes indicated by Experiment 1. Experiment 2 used college students as the subjects, while Experiment 3 used Navy enlisted personnel as subjects. Experiment 3 replicated important features of Experiments 1 and 2.

Experiment 1

Experiment 1 was a pilot study conducted to test the instructional materials, procedures, retention interval, and adequacy of subjects' background information for interpretation of results.

Subjects

The subjects were seven Navy enlisted personnel stationed at the Navy Personnel Research and Development Center. The subjects were randomly assigned to either the structural instruction group (n=4) or the functional instruction group (n=3) and were tested individually. The average educational level of both groups was 12.6 years. Subjects indicated that they had played with model kits fairly frequently, did not know much about electronics, and rated their manual dexterity as very high.

Procedure

Experiment 1 consisted of five stages.

1. Subjects completed the individual difference questionnaire, took the four ASVAB subtests, and were randomly assigned to the structural instruction group or the functional instruction group.

2. All subjects were given the individual parts, one at a time, to study. They were told to ask for the next part only after studying the previous part carefully. The amount of time the subjects spent studying and reading about all the parts was recorded. Next, all subjects took an oral part identification test.

3. All subjects received the appropriate written instructions for assembling the crane at their own pace. They were told to read the instructions carefully. The time they spent reading the instructions was recorded.

4. The subjects were told to assemble the model using the picture and their instructions as needed. Total assembly time was recorded. Subjects completed assembling the model crane if the light flashed when they turned the ON/OFF switch to ON. Each turn of the switch was defined as a trial. The experimenter recorded: the execution of each step and a grade for accuracy and sequence on a checklist; any errors made in the sequence of task steps, in part identification, and in assembling the model; and the number of trials or attempts needed to reach criterion.

5. After 2 weeks, all subjects were given the parts and a picture of the finished product, and asked to assemble the model crane again. The same performance measures were collected.

Results

Although no significance tests were performed, the results suggest an advantage of the functional instruction over the structural instruction on both time and performance measures. The structural instruction group took longer⁴ to study (10:20 minutes) the

⁴Elapsed time such as 10 minutes 20 seconds will be presented as 10:20 minutes in this report.

part names before testing than did the functional instruction group (5:35 minutes). The descriptions of the part functions in the functional instructions appeared to facilitate initial learning and memorizing of the part names.

The average time spent reading the instructions was longer for the functional instruction group (6:54 minutes) than for the structural instruction group (5:40 minutes). The functional instructions were slightly longer than the structural instructions, which could account for this time difference.

The functional group needed 12:29 minutes to learn the part names and read the instructions, while the structural group needed 16:00 minutes. These results agree with the findings of Smith and Goodman (1982) who found faster reading time for the hierarchical functional instruction group than for the linear instruction group. The fact that the functional instruction group read the instructions faster than the structural suggests that some of the steps contain concepts previously mentioned in the instruction or part list and, therefore, require less time to process. The functional explanations for each part appeared to facilitate reading time of the functional instructions.

The total assembly times for initial and retention performances averaged 27:33 and 19:30 minutes for the functional instruction group and 34:09 and 32:45 minutes for the structural instruction group respectively. This time advantage for the functional instruction group over the structural instruction group indicates the importance of evaluating tradeoffs in instructions. For example, initial learning time may be longer for the functional instruction group than for the structural instruction group, but the performance (construction) time is faster for the functional instruction group than for the structural instruction group. If the criterion is performance speed, functional instructions appear to facilitate that outcome.

The functional instruction group averaged 2.6 trials during initial performance and 1.6 trials during retention performance while the structural instruction group averaged 3 trials on both initial and retention performance. The structural instruction group made slightly more critical errors--errors that affect the functioning of the crane--during retention construction than the functional instruction group, while both groups made the same number of noncritical errors as they made during initial construction.

Conclusions

These results indicate that providing qualitative functional explanations in the instructions for performing an assembly task facilitated learning and retention.

Experiment 2

Experiment 2 differed from Experiment 1 in the following major aspects:

1. While assembling the model in Experiment 1, subjects appeared to compare the semantic content of the picture and the instructions systematically because they frequently looked from one to the other. Therefore, in Experiment 2, the subjects built the model without the picture or the instructions on their first trial and with the picture-only on subsequent trials.

2. The retention interval was increased to 1 month to make sure that any existing group differences would be demonstrated.

3. Additional individual difference data were obtained to examine individual difference predictors of instruction adequacy as well as the interactions between predictors of ability and instruction. Subjects were asked how many years of education they had, to rate their mechanical ability, and how often they worked on cars using the same 10-point scale (1 = never or none and 10 = very often or very much).

4. Two additional checklists for evaluating performance were developed. The product checklist measured both the functionality of the finished crane (the light flashing and the hook and string moving up and down) and the accuracy of the structural connections (Baggett, 1983a, 1983b), which includes both critical and noncritical structural connections. The process checklist described the order in which the steps were performed and the type of errors made during each trial. All subjects in the initial learning phase were required to make the model work properly.

Subjects

The subjects were 15 undergraduate students at San Diego State University who participated for partial course credit. All subjects were tested individually by one of two experimenters and randomly assigned to either the structural instruction group (n=7) or the functional instruction group (n=8). The structural instruction group consisted of 2 males and 5 females; the functional instruction group, 2 males and 6 females. Each group averaged 19.5 years of age and 13.5 years of education.

Procedure

The procedures were the same as those used in Experiment 1 except as noted below.

The subjects were told to read the instructions carefully because they would have to assemble the model from memory (without a picture or the instructions). Total assembly time was recorded. The experimenter used a checklist to grade each step for accuracy and sequence. After one unsuccessful trial (the light did not light when the ON/OFF switch was turned to ON), the student received the picture and used it to make any structural or functional corrections. The product and process checklists were used for each trial.

After 1 month, all subjects were given the parts and asked to assemble the crane from memory. A picture of the finished product was provided at the request of the subject. Only three subjects--two from the functional instruction group and one from the structural instruction group--did not request the picture during retention assembly. Subjects' time to assemble the crane was recorded for each trial. Subjects also took the written test on the part names and functions.

Results

The design of the Experiment 2 was a between-groups repeated measures design. Analyses of covariance for the time and performance data were performed with the average self-ratings of the experience and the average overall score on the four ASVAB subtests used as covariates.

Questionnaire and Pretest Scores. No group differences were found on the amount of experience with kits such as erector sets or Legos or in self-ratings of electronics knowledge and manual dexterity. Both groups had limited experience with model kits. On a 10-point scale, they rated their knowledge of electronics as 2.5 (10 = very knowledgeable) and their manual dexterity as 6 (10 = very high).

There was a difference between groups in the self-ratings of mechanical knowledge and frequency of working on cars. On the same 10-point scale (10 = very knowledgeable), the average ratings of mechanical knowledge were 5.3 for the structural instruction group and 3.8 for functional instruction group. The structural instruction group reported having worked on cars fairly frequently, while the functional instruction group reported having worked on cars only once or twice.

Table 4 presents the average scores of the two subject groups in the four ASVAB subtests.

Table 4
Experiment 2: Subjects' Average ASVAB Subtest Scores

ASVAB Subtest	Average Score (%)	
	Structural Instruction Group	Functional Instruction Group
Space perception	78	70
Electronics information	71	52
Mechanical comprehension	77	77
Automotive information	61	55
Overall	70	65

Initial Part-identification Learning Time and Instruction Reading Time. There was a difference between the amount of time the two groups required to learn the name of each model part ($F(1,12)=38.13, p<.001$). Mean times and standard deviations for learning the names of the model parts were 3:00 minutes ($SD=:45$) for the structural instruction group and 6:35 minutes ($SD=1:30$) for the functional instruction group. This time difference was due primarily to the part descriptions read only by the functional group.

The difference in the time both groups took to read the instructions ($F(1,12)=.21, n.s.$) was not significant. The mean time each group spent reading the instructions was 12:34 minutes ($SD=6:00$) for the structural instruction group and 11:54 minutes ($SD=4:39$) for the functional instruction group. The slightly longer reading time of the structural instruction subjects might be accounted for by the notion that these subjects required more time to integrate the information themselves, while the functional instruction subjects received some integrating information in their instructions.

Initial and Retention Part-identification Test Times. The difference in the amount of time the two groups needed to complete the oral part-identification test at both test periods ($F(1,12)=.78, n.s.$) was not significant. However, there was a main effect due to the repeated measure ($F(1,13)=52.33, p<.001$). The structural instruction group took 2:56 minutes ($SD=1:30$), while the functional instruction group took 2:17 minutes ($SD=1:07$) to complete the initial part-identification test. After 1 month, the structural instruction group took 5:20 minutes ($SD=2:26$) and the functional instruction group took 5:00 minutes ($SD=:57$).

Initial and Retention Performance Time. The expected trend toward faster total assembly times for the functional instruction group than for the structural instruction group was not statistically reliable ($F(1,12)=1.15$, n.s.). The difference between initial and retention performance test times ($F(1,13)=1.87$, n.s.) was not statistically reliable. The mean total building times for initial assembly were 28:37 minutes ($SD=14:13$) for the structural instruction group and 23:52 minutes ($SD=7:12$) for the functional instruction group. This trend was also found after the 1-month retention interval when the mean total building times were 23:38 minutes ($SD=5:27$) for the structural instruction group and 21:00 minutes ($SD=6:22$) for the functional instruction group.

The importance of evaluating instructional tradeoffs is indicated by the faster performance time of the functional instruction group. For example, the faster performance of the functional instruction group at both testing times indicates that, although their instructions took longer to learn, they facilitated retention and performance.

Table 5 presents the amount of time spent on each trial by both groups. (Assembly during the first trial was performed without a picture of the finished product; however, the picture was available for subsequent trials.) The difference in the amount of time the groups spent on the first trial was not statistically reliable ($F(1,12)=.26$, n.s.) but there was a significant difference for the retention testing times ($F(1,13)=5.39$, $p<.03$). The amount of time spent on the first trial (without the picture) shows the functional instruction group took more time on initial performance and less time during retention performance than the structural instruction group. On all subsequent trials during initial and retention performance, the functional instruction group took less time than did the structural instructional group.

Table 5

Experiment 2: Mean Assembly Time by Trial for Both Groups

	Mean Assembly Time (Minutes:Seconds)			
	Initial Performance		Retention Performance	
	Structural Group	Functional Group	Structural Group	Functional Group
Trial 1	14:03 (n=7)	15:25 (n=8)	12:23 (n=7)	8:35 (n=8)
Trial 2	12:00 (n=7)	7:38 (n=6)	12:16 (n=6)	11:56 (n=8)
Trial 3	6:00 (n=3)	4:00 (n=5)	3:00 (n=2)	1:51 (n=2)
Trial 4	--	:50 (n=1)	--	2:30 (n=1)

Initial and Retention Performance. Total performance scores were not expected to differ immediately following instruction because the learners had to make the model crane function; but the number of trials to completion was expected to differ for the two groups. The crane was considered to be functioning when the light flashed and the hook and string moved up and down. However, the difference between the groups on the number of trials needed for completion during both initial and retention performance ($F(1,12)=.03$, n.s.) was not statistically reliable. The means for the two groups show no difference between the number of trials needed after initial learning and after the 1-month retention interval ($F(1,13)=.50$, n.s.). The mean number of trials to reach

criterion for the structural instruction group on the initial and retention testing was 2.42 (SD=.53) and 2.14 minutes (SD=.69) respectively. The mean number of trials for the functional instruction group was 2.50 (SD=1.06) after initial learning and 2.37 minutes (SD=.74) after the retention interval.

Table 6 presents the mean number of critical and noncritical errors made at each trial by the two groups during initial and retention performance. Critical errors affect the functioning of the crane; noncritical errors do not affect the functioning of the crane. There was no group difference on the number of critical errors ($F(1,12)=1.31$, n.s.) or the number of noncritical errors ($F(1,12)=.79$, n.s.). On the first trial during the initial performance, the functional instruction group made fewer mean critical errors than the structural instruction group. The reverse was found during the retention performance: The functional instruction group made more critical errors than the structural instruction group. However, subsequent trials with the picture do not show any differences between the groups.

Table 6
Experiment 2: Mean Number of Critical and Noncritical
Errors Made by Both Groups

Trial/Error	Mean Number of Errors			
	Initial Performance		Retention Performance	
	Structural Group	Functional Group	Structural Group	Functional Group
Trial 1	n=7	n=8	n=7	n=8
Critical	5.42	3.62	6.14	7.00
Noncritical	1.00	2.00	1.57	.87
Total	6.42	5.62	7.71	7.87
Trial 2	n=7	n=6	n=6	n=8
Critical	.71	2.66	1.16	.75
Noncritical	1.14	1.33	1.50	1.50
Total	1.85	3.99	2.66	2.25
Trial 3	n=3	n=5	n=2	n=3
Critical	0.00	.60	0.00	.33
Noncritical	.66	1.20	1.50	1.00
Total	.66	1.80	1.50	1.33
Total Critical	6.13	6.88	7.30	8.08
Total Noncritical	2.80	4.53	4.57	3.37
Total Errors	8.93	11.41	11.87	11.45

Retention Part-name-and-function Test Performance. There was a significant difference on the written retention part-name-and-function test performance between the two groups ($F(1,11)=4.80$, $p<.05$). The structural instruction group scored 37 percent while the functional instruction group scored 46 percent. Table 7 shows that the functional

instruction group performed slightly better than the structural instruction group on the written part name-and-function test. This result indicates that the functional explanations are providing the student with a functional representation of the task.

Table 7
Experiment 2: Part Name-and-function Test Results

Test (No. of Items)	Correct Responses (%)	
	Structural Group	Functional Group
Part Name (20)	49	54
Structure (20)	30	31
Function (20)	41	46
Total (60)	40	44

These results are consistent with the findings of Smith and Goodman (1982), who also found faster reading times for the hierarchical/structural and functional instruction groups than for the linear instruction groups. The faster reading times of the functional instruction group over the structural instruction group in Experiments 1 and 2 suggest that some of the steps contain concepts previously mentioned in the instruction or parts list and these steps required less time to process. The parts list for the functional instruction group included explanatory functional information for each part, which appeared to facilitate reading time of those instructions.

Smith and Goodman (1982) suggested that the hierarchical/structural explanations used in their study provided a framework or schema of the task that facilitated learning. A schema is an organized knowledge structure that guides perception and reduces encoding time as well as being a guide for recall. The facilitative effect of the functional instructions shown in Experiments 1 and 2 indicates that having the appropriate schema for the passage content facilitates study as well as retrieval.

Experiment 3

The results from Experiment 2 in conjunction with those of Experiment 1 (pilot study) suggested the need for experimental design modifications. The use of pictures with text had produced significantly more accurate performance of the assembly task by communicating different types of information. It may be that learners presented with redundant information in illustrations and text rely on the illustrations to provide them with a context for the information they extract from text. Therefore, a control group that received only pictures was added to discern the effect of pictures on learning and performance.

The population of highly verbal and academically homogeneous young adults used in Experiment 2 may use the qualitative explanations differently than do other less verbal groups. Therefore, Experiment 3 replicated Experiment 2 using Navy enlisted personnel as subjects.

Subjects

The subjects were 13 Navy enlisted personnel stationed at Naval Training Center, San Diego. All subjects were tested individually by one of two experimenters. The subjects were randomly assigned to the structural instruction group (n=4), the functional instruction group (n=5), or the picture-only group (n=4). The mean age for the subjects was 20; 11 males and 2 females participated.

Procedure

The instructions for the pictures-only group consisted of three pictures of the finished model crane viewed from different angles. The procedures were the same as those used in Experiment 2.

Results

The design of the experiment was a between-groups repeated measures design. Analyses of covariance for the time and performance data were calculated using the experience self-ratings and the average overall score on the ASVAB subtests as covariates.

Questionnaire and Pretest Scores. No group differences were found on the amount of experience with kits such as erector sets or Legos or the self-ratings of manual dexterity, electrical and mechanical knowledge, and the frequency of working on cars. Table 8 presents the average scores of the subject groups on the four ASVAB subtests.

Table 8
Experiment 3: Subjects' Average ASVAB Subtest Scores

ASVAB Subtests	Average Score (%)		
	Structural Instruction Group	Functional Instruction Group	Picture-only Group
Space perception	92	80	68
Electronics information	95	80	83
Mechanical comprehension	94	85	89
Automotive information	67	69	75
Overall	87	78	78.5

Initial Part-identification Learning, Testing, and Instruction Times. Mean times and standard deviations for learning the name of each model part were 3:46 minutes (SD=:52) for the structural instructions group, 7:13 minutes (SD=3:23) for functional instruction group, and 4:44 minutes (SD=1:44) for the picture-only group ($F(2,10)=79.57, p<.001$). This time difference is due primarily to the part description read only by the functional instruction group. There was also a difference in the time the groups took to take the

part identification test: structural instruction group, 7:30 minutes (SD=2:52), functional instruction group, 9:53 minutes (SD=3:34), and picture-only group 6:27 minutes (SD=:52) ($F(2,10)=131.22, p<.001$). The functional instruction group spent more time describing the part functions, presumably as a way of remembering the actual part name.

The mean times each group spent reading the instructions were 14:00 minutes (SD=8:22) for the structural instruction group; 17:28 minutes (SD=4:13) for the functional instruction group; and 3:57 minutes (SD=1:13) for the picture-only group ($F(2,10)=7.52, p<.01$). This difference may be accounted for by the fact that the functional instruction subjects had slightly longer instructional material to read than the structural instruction subjects.

Initial and Retention Performance Time. The total assembly time was expected to be faster for the functional instruction group than for the structural instruction group or the picture-group only. However, the initial mean total assembly times were 38:08 minutes (SD=15:00) for the structural instruction group, 46:21 minutes (SD=50:45) for the functional instruction group, and 33:01 minutes (SD=10:37) for the picture-only group. This time difference was also found after the 1-month retention interval ($F(1,10)=2.98, n.s.$). The mean assembly times after 1 month were 23:15 minutes (SD=8:49) for the structural instruction group, 25:12 minutes (SD=9:20) for the functional instruction group, and 29:13 minutes (SD=10:17) for the picture-only group. The functional instruction group, which demonstrated the biggest gain in time spent, also had the largest amount of variability.

Table 9 presents the amount of time spent on the first trial during initial and retention assembly for the three groups. There was no statistically reliable difference between the groups ($F(2,9)=.29, n.s.$) or the time of testing ($F(1,10)=.26, n.s.$) for the amount of time spent on the first assembly trial.

Table 9

Experiment 3: Time Spent on First Trial by the Three Groups

Instruction Group	Mean Assembly Time (Minutes:Seconds)			
	Initial		Retention	
	Mean	SD	Mean	SD
Structural	14:20	5:28	13:13	4:23
Functional	15:45	9:55	14:03	13:50
Picture-only	13:51	11:51	16:01	13:18

The differences in the amount of time the three groups spent on the first trial after initial learning and retention interval were not consistent. The large amount of variability observed for the functional instruction and the picture-only groups was not observed for the structural instruction group.

Initial and Retention Performance. Total performance test scores were not expected to differ immediately following training because the students were required to make the model crane function. However, the number of trials to completion was expected to differ for the three groups.

The means for all the groups show no differences in the number of trials needed to make the crane function either after initial learning or the retention interval. The mean number of trials to reach criterion on the initial learning and the retention testing for the structural instruction group was 2.75 and 2.50 respectively; for the functional instruction, 4.00 and 3.80 respectively; and for the picture-only group, 4.75 and 2.75 respectively.

The total number of errors made during assembly was not significantly different for the three groups ($F(2,10)=.05$, n.s.). Also, no difference was found for the number of errors made during initial or retention assembly ($F(1,10)=.05$, n.s.). The mean number of errors made by the structural instruction group during initial assembly was 5.25 ($SD=4.57$) and during retention assembly was 6.00 ($SD=3.36$); for the functional instruction group, 5.20 ($SD=2.28$) and 5.00 ($SD=3.39$) respectively; and for the picture-only group, 5.25 ($SD=3.40$) and 5.50 ($SD=2.46$) errors respectively.

Retention Part-name-and-function Testing Times. Before and after assembly for the retention phase, subjects took a written test requiring them to name each part and describe its structure and function. The mean times to complete the parts test before and after assembly for the structural instruction group were 22:14 ($SD=6:38$) and 13:05 minutes ($SD=5:26$) respectively; for the functional instruction group, 19:20 ($SD=4:26$) and 17:17 minutes ($SD=4:58$) respectively; and for the picture-only group, 30:10 ($SD=27:55$) and 12:52 minutes ($SD=2:04$) respectively. There was a significant difference ($F(2,9)=58.00$, $p<.001$) among the groups on part-name testing time and between the two testing periods for the three groups ($F(1,10)=5.06$, $p<.05$).

The analysis of covariance on part names showed no group or test taking time differences. The analysis for the structure answers revealed no group differences, but a time difference ($F(1,10)=26.66$, $p<.001$) and an interaction ($F(2,10)=4.04$, $p<.05$). The test scores for structure before retention assembly were 62 percent for the structural instruction group, 77 percent for the functional instruction group, and 75 percent for the picture-only group. The scores for structure after retention assembly were 68 percent for the structural group, 86 percent for the functional group, and 97 percent for the picture-only group.

The group differences in naming the function of each part ($F(1,10)=4.10$, $p<.05$) and in the test taking time ($F(1,10)=20.56$, $p<.001$) were significant. The average scores on naming the function of each part before assembling the model were 56 percent for the structural instruction group, 68 percent for the functional instruction group, and 65 percent for the picture-only group. After assembling the model, the scores for naming the function of the parts were 61 percent for the structural instructions group, 89 percent for the functional instruction group, and 85 percent for the picture-only group.

Retention Qualitative Test. A test on the qualitative understanding of the functioning of the model crane was administered after the subjects had assembled the model and taken the part-identification test during the retention phase. The test asked the subjects to predict the functioning of the model crane if certain structural changes were made. The scores were 43 percent for the structural instruction group, 57 percent for the functional instruction group, and 35 percent for the picture-only group.

General Discussion

The two main differences between Experiments 2 and 3 were the type of subjects and the addition of the picture-only group in Experiment 3. Experiment 2 used college undergraduates, while Experiment 3 used Navy enlisted personnel as subjects. In this discussion, we will consider the amount of prior knowledge and experience of working with model kits.

Questionnaire and Pretests

In Experiments 2 and 3, the undergraduate subjects reported slightly higher grade point averages than did the military subjects. The undergraduate subjects were predominantly females; and the Navy subjects were mostly males. The Navy subjects were about two years older than the undergraduates. On the questionnaire, the Navy subjects rated themselves as having more experience with model kits, more experience with electronics, and more mechanical knowledge. They scored higher on the four subtests of the ASVAB than did the undergraduates.

The impact of prior knowledge on learning new material was not the focus of these studies. No significance tests were performed for the performance difference between the two samples because of differences in some of the measures used in Experiments 2 and 3. However, the subjects differed in background and prior knowledge of building models. The undergraduates were less experienced than the Navy subjects and had almost no prior experience in model building.

Initial Part-identification Learning and Instruction Reading Times

In general, the Navy subjects took longer than the undergraduates to learn the part names and to read the instructions. For both Navy and undergraduate subjects, the functional instruction groups took longer than the structural instruction groups to learn the part names. These results are not surprising when the amount of material each group had to read is considered. A possible explanation for this finding is that the functional instruction included added functional descriptions of each part, while the structural instruction did not.

However, the undergraduates in the functional instruction group read the instructions faster than did those in the structural instruction group. The reverse was true for the Navy subjects. Prior knowledge and experience may account for this finding. The undergraduates, who had less experience and prior knowledge than the Navy subjects, seemed to benefit more from the functional qualitative instruction than from the structural qualitative instruction. The reverse was found for the Navy subjects. Having some experience with model kits reduced the need for more qualitative functional explanations. The picture-only group took the least amount of time studying the pictures, taking the part identification test, and reading the instructions. The functional instruction group had slightly more material to read than the structural instruction group and both explanation groups had longer instructions than the picture-only group.

The outcome for the undergraduates (Experiment 2) replicates the results of Smith and Goodman, whose subjects were all female and, in general, not experienced with assembly tasks. They found that steps were read faster with hierarchically organized functional instructions than with linear instructions. The notion of prior activation

explains the findings in instruction reading time for the undergraduates in Experiment 2. The functional instructions facilitated reading time by providing an explanatory schema or framework for the steps. This mechanism of prior activation suggests that some steps contain concepts that were previously mentioned in an explanatory statement and these preactivated steps require less processing. Prior activation, however, did not play a role in the performance of the more experienced Navy subjects in Experiment 3.

Initial and Retention Performance Time

In general, the Navy subjects took longer to build the model crane than the college subjects at both testing times. The total building time was expected to be faster for the functional instruction group than for the structural instruction group. In Experiment 2, the functional instruction group assembled the model faster than did the structural instruction group at both testing times. On the other hand, in Experiment 3 the reverse was true: The structural instruction group assembled the model faster than the functional instruction group at both testing times. The picture-only group was the fastest in initial assembly and took the longest after the retention interval. Although there was no difference between the structural and the functional instruction groups on initial performance time, both groups performed much faster than the picture-only group after the retention interval.

In both experiments, the retention performance time was shorter than the initial performance time because the instructions provided the subjects with a representation of the task that facilitated retention performance.

For the first trial assembly, the undergraduate functional-instruction group was slower than the structural instruction group but, after the retention interval, the functional instruction group performed much faster. In the Navy sample, the structural instruction group performed the first trial assembly faster than the functional instruction group both initially and after the retention interval. However, the differences were very small.

Initial and Retention Performance

Total performance test scores of the functional and structural instruction groups were not expected to differ immediately following training because the students had to make the crane function. This was true in both experiments. The number of trials to reach criterion was expected to be higher for the structural instruction group than for the functional instruction group. The functional and structural instruction groups of the undergraduate sample did not differ in the number of trials to reach criterion during initial and retention performance; however, in the Navy sample, the functional instruction group required more trials to reach criterion than did the structural instruction group during initial and retention performance.

The functional and the structural instruction groups of both the undergraduate and Navy samples made the same total number of errors during assembly. There was no difference in the number of critical and noncritical errors made by the undergraduate functional and structural instruction groups. In general, the number of errors increased slightly during the retention performance for both instruction groups.

In Experiment 3, the types of errors made during assembly were classified as errors of order, error of orientation, or a combination of the two types. No significance tests were performed. The functional instruction group made fewer errors of order than the

structural instruction group during both initial and retention performance. However, the functional group made more orientation errors during initial performance and fewer orientation errors during retention performance than did the structural instruction group. The picture-only group was expected to make fewer orientation errors than both of the other two groups because of the spatial information conveyed in the pictures. However, the picture-only group made the same number of orientation errors as the functional instruction group.

Smith and Goodman's execution errors consisted of errors made in the order or sequence of step execution. They found that the hierarchical functional explanation group made fewer execution errors than the linear group. Experiment 3 demonstrated the same finding for the Navy subjects. The functional instruction group made fewer errors of order during both initial and retention performance than did the structural instruction group. It can be concluded that subjects who received supplemental explanations developed a representation of the steps that allowed them to use some of this higher level information as constraints in executing some of the steps, which reduced the frequency of errors. In other words, the potential for vagueness in descriptions of procedural steps can be reduced by adding constraining information in the form of functional explanatory material.

Retention Part-identification Test Performance

In general, the Navy subjects performed better than the undergraduate subjects in describing the structure and function of each part. In both samples, however, the functional instruction group performed better on the test than did the structural instruction group. This is an indication that the instructional variable manipulation was successful.

Summary

The results suggest that the advantages of the qualitative explanations depend on the user's general expertise and familiarity with assembling models. The undergraduate subjects rated themselves lower in prior knowledge and experience with model construction than did the Navy subjects. The undergraduate subjects from Experiment 2 who received functional instructions demonstrated faster retention performance than did the Navy subjects who received functional instructions. Possibly, the functional explanation is best for subjects who have little prior knowledge and limited experience with models.

Although there is a lack of experimental studies on the effects of prior knowledge and experience, Reigeluth (1980) suggests that the success of later recall depends on the amount of elaborating during study--the elaboration hypothesis. Elaborations or supplemental qualitative explanations facilitate memory. They allow students to infer the procedures, develop their own learning and memory strategies, identify goal information, convey important constraining information, and increase meaningfulness of the material. One important aspect of supplemental explanations is that they provide additional information that relates to procedures. In both samples, the functional instruction groups took more time to read the instructions than did the structural instruction groups. However, the functional instruction groups did not perform better during retention than the structural instruction groups.

The results from Experiment 2 indicate the facilitative effect of functional instruction on learning, retention, and performance; however, the results from Experiment 3 did not replicate the facilitative effects. One possible explanation for this finding is the

different study strategies used by undergraduates and Navy personnel. Although the initial learning criterion required subjects to make the model function, none of the skills for actually assembling the model were highly automated. To some extent, the model was a new device to all the subjects. However, the study strategy for the undergraduates appeared to follow a memory retrieval mode, while the Navy personnel seemed to assemble the model in a problem-solving mode. The best characterization of assembling a model from memory seems to be that the Navy subjects solved problems by determining what constraints need to be satisfied along the way.

CONCLUSIONS

The development of the taxonomy of qualitative explanation by types of procedural tasks is useful for investigating instructional design for procedural tasks.

Research using procedural tasks has focused mainly on assembly and operator tasks and has been concerned with the organization, not the qualitative content, of the instructional materials (Baggett, 1983a, 1983b; Kieras, 1983; Smith & Goodman, 1982). Because of this emphasis on sequence or organization, little information is available about the types of information that should be included for various tasks.

The research presented here focused on whether instructions should include additional qualitative information about the structure and function of a task to facilitate learning and retention of the task. Although the results from Experiments 1 and 2 indicate the facilitative effects of including functional explanations, Experiment 3 results did not. The instructional manipulation appeared to work as demonstrated by performance on the retention part-identification and the qualitative tests. The lack of a real performance difference in Experiment 3 between the control (picture-only) group and the functional instruction group could indicate a ceiling effect. The lack of a performance difference could also be attributed to the similarity of the explanations and suggests the difficulty of identifying the appropriate qualitative explanation.

Although Smith and Goodman (1982) found the hierarchical/structural group performed better than for the linear group, this performance difference was replicated only by undergraduates and not by the more experienced Navy enlisted personnel. However, in Experiments 1 and 2, the functional instruction groups did perform better than the structural instruction group.

For simple assembly tasks, additional explanations appear not to make a difference. Rote learning of procedures is better than qualitative explanations that require a lot of facts and involve excessive processing load. If the rote learning involved can take advantage of surface features of the model such as mnemonic levels, then rote learning of procedures is better than providing qualitative explanations. For a more difficult or complex assembly task, supplementary qualitative explanations would facilitate retention and performance.

RECOMMENDATIONS

The results indicate a need for a measure of instructional cost effectiveness--tradeoffs in time to instruct versus time to perform. This measure should make explicit the advantages, disadvantages, and tradeoffs in training time and performance for the various types of explanations. The conditions under which a particular technique can be

used to best advantage and the functional equivalence of various techniques that might be used for achieving a particular goal should be outlined. A body of knowledge that takes these various concerns into account in a more direct manner is needed.

The implication of this research is for instructional developers to recognize the interactions between the learner's knowledge structures, the structure of the information content in the instructional material, and the structure of the task when developing and designing instruction. This research focused on the structure of the instructional materials and of the task as indicated by the taxonomy of procedural tasks by qualitative explanations (see Table 2). Future directions should explore other types of tasks and prescribed explanations and the practical question of how much information actually helps do the task. Instructional developers should consider the tradeoffs in training time and performance for the various types of explanations when designing instruction.

Further, this research points out the importance to training designers of considering prior experience and background when prescribing guidelines for instruction. Instructional designers are encouraged to consider the interactions between the learner's knowledge structures, the structure of the information content, and the structure of the task when developing instruction.

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APPENDIX
INSTRUCTIONS FOR EXPERIMENTAL ASSEMBLY TASK

Linear/Structural Instructions A-1
Functional Instructions A-6

Linear/Structural Instructions

Today we are going to give you some instructions on how to build a fairly complicated object from a model kit. The object you will build is a model crane which is used to raise and lower other objects. After reading the instructions you will be asked to build the model from memory, so try to learn as much as you can.

Before actually building the model, you will be shown each piece and told its name. You should learn the names of each piece so you know them on sight. You will be required to identify each part name from the actual part.

Now turn the page and begin studying the different parts.

PARTS LIST

The following is a list of the part names and a picture of each part needed to assemble the model crane:

The number in parenthesis is the number of each part needed to assemble the crane.

- 1) Motor Capsule (1)
- 2) Speed Reduction Capsule (1)
- 3) Worm Gear Capsule (1)
- 4) Rotary Switch Capsule (1)
- 5) Empty Capsules (3)
- 6) Octagonal connectors (10)
- 7) Small Bar Connector (2)
- 8) Large Bar Connector (1)
- 9) Coupler (2)
- 10) Coupler Caps (2)
- 11) Large Battery Case (1)
- 12) Switch Box (1)
- 13) Leads (5)
- 14) Lamp (1)
- 15) Small Wheel (1)
- 16) Gear Wheels (2)
- 17) Chain (62links)
- 18) Float (4)
- 19) Winding drum (1)
- 20) Hook and String (1)

The following steps describe the way in which the model crane should be built. Please read each step carefully, because you will be required to build the model from memory. A picture of the finished working model crane is provided on the last page of this booklet.

Step 1: Select motor capsule and a blue lead. Position motor capsule so that one blue socket is facing to your left and one blue socket is facing down. The motor in the capsule should be vertical.

Step 2: Insert the blue lead in the bottom motor capsule socket.

Step 3: Select 1 octagonal connector, run the lead through it and attach it to the bottom of the motor capsule.

Step 4: Select two empty capsules. Open the empty capsule (by taking the octagonal connector(s) off) and run the blue lead through the top of it and through the capsule so that it comes out of the hole facing to your left. Connect the empty capsule to the bottom of the motor capsule using the connector that is already at the bottom of the motor capsule. Set this assembly aside.

Step 5: Select 2 float devices and a small connector bar. Attach the two floats to each end of the connector bar so that the floats come off the bar at an angle.

Step 6: Select the remaining 2 float devices and small connector bar, and attach the two floats to the connector bar in a similar manner.

Step 7: Select a second empty capsule and attach it using octagonal connectors to the right side of the first empty capsule (the side opposite where the blue lead is coming out). Connect the two bar connectors with floats to the sides of the empty capsules.

Step 8: Select the speed reduction capsule and attach the side that moves the easiest when turned with your fingers to the top of the motor capsule using octagonal connectors. In order to get

power to the crane you must connect the side that turns the easiest to the top of the motor capsule. Be sure the gears are firmly locked together.

Step 9: Select the 2 AA batteries and the battery case. Insert the batteries in the case and snap the battery case closed.

Step 10: Attach the battery case to the right side of the motor capsule and the speed reduction capsule using octagonal connectors. The battery case should be positioned so that the spring is on the bottom.

Step 11: Select rotary switch capsule and attach it to the top of the speed reduction capsule, using octagonal connectors. The rotary switch capsule should be placed so that one of the blue sockets is facing toward you and the other blue socket is facing away from you.

Step 12: Select worm gear capsule and attach it to the top of the rotary switch gear capsule, using octagonal connectors. The grey ends connect with the shaft and therefore need to be connected to the top of the rotary switch in such a way that one white side is facing toward you and the other white side facing away from you.

Step 13: Select an empty capsule and attach it to the top of the worm gear capsule, using octagonal connectors.

Step 14: Select large bar connector, a coupler, a coupler cap, and a gear wheel and attach the coupler to one end of the bar connector.

Step 15: Put the gear wheel on the coupler and attach the coupler cap.

Step 16: Select chain links and connect the links.

Step 17: Select another gear wheel, coupler, coupler cap. Attach the coupler to the connector bar, the gear wheel (before attaching the gear put the chain around the gear) to the coupler and

complete with the coupler cap.

Step 18: Select the front gear wheel winding drum and insert it opposite the front gear wheel.

Step 19: Select hook and string and attach to the winding drum.

Step 20: Select the switch box and attach it to the right side of the rotary switch capsule using octagonal connectors.

Step 21: Select a red lead and plug one end into the top socket of the switch box labeled "in" and plug the other end of the red lead to the top socket of the battery case.

Step 22: Select a blue lead and plug one end into the bottom socket of the switch box labeled "in", and the other end plug into the bottom socket of the battery case.

Step 23: Select a red lead and plug one end into the top socket of the switch box labeled "out" and plug the other end into the blue socket of the motor capsule.

Step 24: Take the blue lead from the front of the bottom empty capsule (which is plugged into the blue socket of the motor capsule) and plug it into the bottom socket of the switch box labeled "out".

Step 25: Select lamp and lead and plug into the topmost empty capsule.

Step 26: Connect one lamp wire lead to the top socket on the back of the switch box. And connect the other lead from the lamp to the blue contact of the rotary switch capsule.

Step 27: Select red lead and plug one end into the other blue socket of the rotary switch capsule and plug the other end into the bottom socket on the back of the switch box.

Step 28: Turn on.

Functional Instructions

Today we are going to give you some instructions on how to build a fairly complicated object from a model kit. The object you will build is a model crane which is used to raise and lower other objects. After reading the instructions you will be asked to build the object from memory , so try to learn as much as you can.

The object to be constructed is called a model crane. The crane is built with a series of capsules each having distinct *mechanical or electrical* functions. Get to know the different capsules and their capabilities. The electrical connections are made by plugs and sockets.

Before actually building the model, you will be shown each piece, told its name, and its function. You should learn the names and functions of each piece so you know them on sight. You will be required to identify each part name from the actual part.

Now turn the page and begin studying the different parts, functions, and the part names.

PARTS LIST

The following is a list of the part names, a functional description of each parts and each part needed to assemble the model crane:

The number in parenthesis is the number of each part needed for the crane.

- 1) Motor Capsule (1) - This capsule contains a built-in motor which is powered by an external battery. It is designed to turn a shaft. It can turn a shaft in either directions. Water will damage the motor, take care that it does not get wet.
- 2) Speed Reduction Capsule (1) - This capsule reduces the speed of the shaft driven by the motor, however, it increases the torque or turning power. To function correctly, the input side of this capsule must be connected to the shaft. If, by accident, the output side of this capsule is connected to the motor it will not run. To determine which is the input shaft turn both sides in turn with your fingers. The input side is the one which turns easily.
- 3) Worm Gear Capsule (1) - This capsule is also a speed reduction capsule, however, it also changes the direction of the motive force. It reduces the shaft speed and changes the direction of the motive force 90 degrees. To function correctly the gray sockets of this capsule are coupled with the sockets of other capsules.
- 4) Rotary Switchs Capsule (1) - This capsule alternately opens and closes a switch as the shaft rotates. It is used to cause a light to blink off and on.
- 5) Empty Capsules (3) - These capsules do not contain internal parts. They are used for the base of the crane, as well as, to gain additional heighth at the top of the crane.
- 6) Octagonal connectors (10) - These connectors are used to attach one major piece to another, they snap on and off easily in a push/pull fashion.
- 7) Small Bar Connector (2) - These connectors have 2 connecting holes and are used to connect the floats at the base of the crane.
- 8) Large Bar Connector (1) - This connector has 2 connecting holes, but is twice the size of the small bar connector. It also has a hole in the middle. It is used as the arm of the crane.

- 9) Coupler (2) - These couplers are used to build the gear assembly which moves the pulley chain.
- 10) Coupler Caps (2) - These caps are used to seal the connection between the coupler and the gear wheels.
- 11) Large Battery Case (1) - A plastic case in which the batteries are placed. The batteries provide the motor with power to drive the crane.
- 12) Switch Box (1) - The switch box is used to change direction of the crane and to turn the crane on/off.
- 13) Leads (5)- These electrical leads are used to connect the battery case to the motor capsule, the battery and motor to the switch box, and the rotary switch capsule to the switch box.
- 14) Lamp (1)-A flashing lamp that is positioned at the top of the crane.
- 15) Small Wheel (1)-A small wheel which the crane lifts.
- 16) Gear Wheels (2)-Gear wheels are used at both ends of the large connector bar. They are attached using couplers and coupler caps. This assembly moves the pulley chain.
- 17) Chain (62 links)-The links make up the chain that is attached to the two gear wheels.
- 18) Float (4)- The floats are the base of the crane and are assembled using two empty capsules and the two small connector bars.
- 19) Winding drum (1)- This drum is used as the spool on which the hook and string are wound. It is connected to a small wheel gear and coupler.
- 20) Hook and String (1)- The hook and string raise and lower the object attached to the hook.

The following steps describe the way in which the model crane should be built. Please read each step carefully, because you will be asked to build the model from memory. A picture of the finished crane is provided on the last page of this booklet.

Step 1: Before starting to assemble the base of the crane, select motor capsule and a blue lead. Position motor capsule so that one blue socket is facing to your left and one blue socket is facing down. The motor in the capsule should be vertical, with the output socket of the motor capsule on top.

Step 2: Insert the blue lead in the bottom motor capsule socket.

Step 3: Select 1 octagonal connector, run the lead through it and attach it to the bottom of the motor capsule.

Step 4: Select one empty capsules. Open the empty capsule (by taking the octagonal connector(s) off) and run the blue lead through the top of it and through the capsule so that it comes out of the hole facing to your left. Connect the empty capsule to the bottom of the motor capsule using the connector that is already at the bottom of the motor capsule. Set this assembly aside.

Step 5: To assemble the base of the crane select 2 float devices and a small connector bar. The floats serve as the legs of the crane. Attach the two floats to each end of the connector bar so that the floats come off the bar at an angle.

Step 6: Select the remaining 2 float devices and small connector bar, and attach the two floats to the connector bar in a similar manner.

Step 7: To complete the base for the crane, select a second empty capsule and attach it using octagonal connectors to the right side of the first empty capsule (the side opposite where the blue lead is coming out). Connect the two bar connectors with floats to the sides of the empty capsules.

Step 8: Select the speed reduction capsule and attach the side that moves the easiest when turned with your fingers to the top of the motor capsule using octagonal connectors. In order to get power to the crane you must connect the side that turns the easiest to the top of the motor capsule. The side that turns the easiest is the input shaft of the speed reduction capsule. The speed reduction capsule reduces the shaft speed but increases the torque or turning power. The output shaft or the side that is difficult to turn with your fingers shows the reduction of shaft speed as a result of passing through the speed reduction capsule. Be sure the gears are firmly locked together.

Step 9: Select the 2 AA batteries and the battery case. Insert the batteries in the case and snap the battery case closed. The batteries provide the motor capsule with electrical power.

Step 10: Attach the battery case to the right side of the motor capsule and the speed reduction capsule using octagonal connectors. The battery case should be positioned so that the spring is on the bottom. The battery case should be positioned with the positive side up.

Step 11: Select rotary switch capsule and attach it to the top of the speed reduction capsule, using octagonal connectors. The rotary switch capsule should be placed so that one of the blue sockets is facing toward you and the other blue socket is facing away from you. As the shaft rotates the rotary switch capsule alternately opens and closes the switch.

Step 12: Select worm gear capsule and attach it to the top of the rotary switch gear capsule, using octagonal connectors. The grey ends connect with the shaft and therefore need to be connected to the top of the rotary switch in such a way that one white side is facing toward you and the other white side facing away from you. The worm gear capsule reduces the speed and changes the direction of the motive force. This capsule changes the direction of the power to the side and provides the arm of the crane with power to drive the chain.

Step 13: Select an empty capsule and attach it to the top of the worm gear capsule, using octago

nal connectors.

Step 14: To begin assembling the arm of the crane, select large bar connector, a coupler, a coupler cap, and a gear wheel and attach the coupler to one end of the bar connector.

Step 15: Put the gear wheel on the coupler and attach the coupler cap.

Step 16: Select chain links and connect the links.

Step 17: To complete the arm assembly of the crane, select another gear wheel, coupler, coupler cap. Attach the coupler to the connector bar, the gear wheel (before attaching the gear put the chain around the gear) to the coupler and complete with the coupler cap.

Step 18: Select the front gear wheel winding drum and insert it opposite the front gear wheel.

Step 19: Select hook and string and attach to the winding drum.

Step 20: Select the switch box and attach it to the right side of the rotary switch capsule using octagonal connectors.

Step 21: In order to make electrical connections between the battery and the switch box two leads from the battery are plugged into the "in" sockets of the switch box. Select a red lead and plug one end into the top socket of the switch box labeled "in" and plug the other end of the red lead to the top socket of the battery case. This connects the top socket of the switch box labeled "in" which is positive to the top socket of the battery case which is also positive.

Step 22: Select a blue lead and plug one end into the bottom socket of the switch box labeled "in", and the other end plug into the bottom socket of the battery case. This blue lead connects the negative socket or bottom socket of the switchbox labeled "in" with the negative side of the battery case.

Step 23: In order to make electrical connections between the motor and the switch box, two leads from the motor capsule are plugged into the sockets on the switch box labeled "out". Select a red lead and plug one end into the top socket of the switch box labeled "out" and plug the other end into the blue socket of the motor capsule. This red lead connects the positive socket of the switch box to the positive socket of the motor capsule.

Step 24: Take the blue lead from the front of the bottom empty capsule (which is plugged into the blue socket of the motor capsule) and plug it into the bottom socket of the switch box labeled "out". This blue lead connects the negative socket of the motor capsule (the ground) to the negative socket of the switch box.

Step 25: Select lamp and lead and plug into the topmost empty capsule.

Step 26: For blinking light action connect one lamp wire lead to the top socket on the back of the switch box. And connect the other lead from the lamp to the blue contact of the rotary switch capsule.

Step 27: Select red lead and plug one end into the other blue socket of the rotary switch capsule and plug the other end into the bottom socket on the back of the switch box. Blinking light action occurs only while the rotary switch capsule is connected to the lamp as instructed.

Step 28: Turn on.

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