UNDERSTANDING THE SYSTEM: THE KEY TO SUSTAINED TASK COMPETENCE?

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ABSTRACT

The present study investigates which kind of explanations during instruction promotes the acquisition and retention of operating skill. Subjects learned to direct a ship from one side of a simulated lock to the other by mouse-clicking controls on a computer monitor. One group simply memorized the task actions. A second group received task structure information, and a third group received additional conceptual information on underlying system principles. Providing structural or conceptual information did not significantly facilitate the acquisition and retention of skill. there are indications that stronger effects may be obtained by using a more refined experimental procedure.

INTRODUCTION

The pace of technological development has accelerated extensively in recent years and the introduction of advanced technology into the work place has changed the character of professional jobs substantially. The operational power of civil and military organisations is becoming increasingly more determined by the competence of its personnel in acquiring and retaining skill in operating devices. One of the good properties of operating tasks is that they can be learned relatively quickly, even if the set of operations is complex (Kieras 1990). Problematic is, however, that skill in procedural tasks deteriorates very rapidly during periods of no-practice (Christina and Bjork 1991). The present paper investigates whether and how acquisition and retention of competence in operating tasks is affected by different types of instruction.

In order to be able to execute a task successfully, the performer must have a mental representation of the task. This representation may be different in nature, varying from elementary and superficial (e.g. knowledge of the series of individual task steps) to extended and comprehensive (e.g. full understanding of system components and functions, knowledge of the relationships between system functions, task organization, and task execution, knowledge of the impact of environmental conditions on task performance etc).

Much research has been carried out to determine the kind of explanations that are most appropriate for promoting the acquisition and retention of complex procedural operating tasks (e.g. Catrambone 1995; Dixon and Gabrys 1991; Johnson 1981; Kieras and Bovair 1984; Mark and Greer 1995). An operationally defined taxonomy of qualitative explanations has been developed by Stevens and Steinberg (1981), and Smith and Goodman (1984), differentiating among linear, structural, and functional explanations. Linear explanations tell a trainee simply what steps to follow and in what order, thus establishing a very elementary mental representation that is limited to superficial features of the task. Structural explanations clarify how different task components fit together. This type of explanations help the learner to structure the operating procedures on a purely formal level (operational knowledge). Functional explanations provide the information that is required to understand the principles underlying the system functions, thus enabling the learner to develop a conceptual understanding of system and task (conceptual knowledge). For example, informing a trainee that

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taking a picture of an object moving rapidly at right angles to the photographer's viewpoint will produce a blurred picture if the camera's display indicates 125 or lower, is providing operational knowledge. Explaining that the number 125 refers to the shutter time (1/125s), that the film will be exposed as long as the shutter is open, and that the object will cover a substantial distance between opening and closing of the shutter, is providing conceptual knowledge that can be used to infer the correct procedure (decreasing shutter time).

Konoske and Ellis (1986) compared the effectiveness of a combination of linear and structural explanations to that of functional explanations in an assembly task using Navy students. In one of two experiments, they found that the functional explanation group showed superior learning and retention performance compared to the group that received linear/structural explanations only. The observation that subjects unfamiliar with the task domain benefitted especially, supports the notion that conceptual understanding is necessary to infer the correct actions. The researchers were, however, unable to replicate these findings in a second experiment. The authors suggest that the replication-failure is due to ceiling effects: all three groups obtained high scores on the criterion variables.

The present study continues the study into the kind of explanations that promote the acquisition and long-term retention of operating skill. Subjects learned to direct a ship from one side of a simulated lock to the other by mouse-clicking controls on a computer monitor. The required sequence of actions depended upon the sailing direction of the ship and the water level in the lock. A total of four sets of procedures were to be learned, varying in length from 14-17 steps. One group learned only the list of task actions (linear group). A second group received operational information on the system's architecture and task organization (structural group). The third group received, in addition to operational information, conceptual information on system processes enabling them to understand the logic of the task (functional group). All were trained until criterion and retested after a period of four weeks.

It can be argued that task structure knowledge helps organizing new knowledge in memory, and therefore primarily facilitates learning. However, in order to retrieve task-associated knowledge successfully, the performer needs a conceptual understanding in order to reconstruct actions which might otherwise not remembered. The hypothesis tested is thus that task structure knowledge facilitates skill *acquisition*, and that conceptual understanding is needed for *maintaining* proficiency over a period of no practice.

METHODS

SUBJECTS

44 Subjects were recruited from schools for vocational training and from advanced elementary education (age 15-17 years). They were paid Dfl 60,- for participating.

TASK

Subjects directed a ship from one side to the other of a simulated lock by mouse-clicking controls on a computer monitor (see picture). Four sets of procedures (14-17 steps) were to be learned.

DESIGN

The *linear* group memorized the procedures. The *structural* group (task-structure knowledge only) learned the subprocedures and their constituent actions. The *functional* group received additional conceptual information on system processes (task-structure *and* conceptual knowledge).

PROCEDURE

Acquisition phase: The acquisition phase involved instruction, demonstration, guided practice and independent practice. Instruction entailed information on the relationships between system characteristics and task demands (functional group only), how the tasks consists of logical subtasks (functional and operational groups only), and the operations to be performed (all groups). The correct action sequence for one of the four

operating procedure was demonstrated autonomously by the program, but at a subject-dictated pace. Then, subjects performed the task themselves, but actions were prompted by the program (guided practice). Immediate corrective feedback was provided in case of an error. Guidance and feedback information were in the same format as the earlier received instruction. Finally, subjects had to perform the task independently, without help, but again, corrective feedback was provided in case of an error. After completion, the next trial automatically started. Independent practice was repeated until three errorless task performances were achieved. Then the next of the four operating procedures was demonstrated. The above described course of events continued until all four operating procedures were performed at criterion.
Retention phase: After four weeks of no practice, subjects returned for a retention test. This time, errors were indicated by a short beep only; no other feedback was provided. Subjects corrected their error and then proceeded with the task trial. Again, after completion, the next trial automatically started. The operating procedure presented varied from trial to trial and continued until the subject accomplished three errorless task performances. Order of presentation was balanced across subjects and groups. Following the retention test, subjects were interviewed to examine their understanding of a lock system, and to assess their prior experience with locks.

DEPENDENT VARIABLES

Number of trials needed to reach criterion, number of errors, mean latency for correct actions.

RESULTS

In general, subjects had no or very little prior maritime experience (34 none, 6 few, and 4 plenty). The dependent variables (see Table) were entered in MANOVA's with type of instruction (3) as between-subjects factor.

	Elaborative explanation instruction				Superficial explanation instruction			
	blocked training		mixed training		blocked training		mixed training	
	blocked retention	mixed retention	blocked retention	mixed retention	blocked retention	mixed retention	blocked retention	mixed retention
nr of trials	16.6 (2.4)	20.8 (5.8)	18.3 (5.9)	19.3 (4.1)	18.7 (4.3)	23.2 (9.2)	19.6 (6.1)	18.5 (3.4)
nr of errors	3.3 (2.6)	10.9 (17.8)	8.4 (11.7)	4.5 (2.6)	5.5 (5.7)	14.7 (9.9)	7.2 (8.4)	5.8 (4.0)
time to action (s)	8.2 (2.1)	10.5 (4.1)	7.8 (1.8)	8.8 (2.2)	8.4 (2.2)	7.8 (2.3)	7.1 (1.9)	7.6 (2.0)
runtime trial (s)	254 (35)	321 (135)	252 (56)	262 (48)	241 (45)	284 (51)	233 (38)	248 (50)

LEARNING PHASE

An over-all effect of Type of Instruction was found ($F(6,76)=2.5$, $p<.05$). Paired comparisons showed a near-significant difference between the structural and the functional group ($F(3,37)=2.5$, $p=.074$). Univariate analyses showed that the functional group took more time between successive task actions ($F(1,39)=6.9$, $p<.05$), possibly because they were consulting their mental representation of system and task. The comparison between the functional and the linear group showed a significant difference ($F(3,37)=3.9$, $p<.05$). Univariate analyses showed that the longer delays between task actions for the functional groups was responsible for this effect ($F(1,39)=8.0$, $p<.01$). Comparing the structural group to the linear group produced no significant differences, thus failing to support the notion that knowledge of the task structure facilitates skill acquisition.

RETENTION PHASE

There was no over-all effect of Type of Instruction. The only paired comparison showing a significant difference was between the structural and the linear group ($F(3,38)=3.0$, $p<.05$). Univariate analyses showed that the linear group needed more trials to relearn the task to criterion ($F(1,40)=3.6$, $p=.067$). The number of errors on the first retention trial were 22.2, 16.9, and 13.7 for the linear, structural, and functional group (n.s.). The number of errors decreased across trials ($F(11,38)=7.3$, $p<.01$), but the pace was identical across groups (see Figure).

** Figure about here ***

No other between-subjects effects were obtained. Thus, the hypothesis that instruction aiming at conceptual understanding facilitates sustained task proficiency over periods of no practice was not supported.

INTERVIEW

Following the retention test, subjects were interviewed to examine their level of system and task understanding. Despite our efforts to provide comprehensive instruction, results showed that many subjects had a very superficial, and often incorrect, understanding of the system's goal and principles. Regrettably, compared to the other two groups, subjects in the functional group did not have a superior understanding of the system.

DISCUSSION

The predictions that instruction on the task structure facilitates skill acquisition, and that providing additional conceptual information facilitates long term retention, were not confirmed. This outcome may be interpreted as (a) compared to simple memorizing, providing additional information during instruction does not lead to superior acquisition or retention of task performance; or (b) the present experimental procedure was not sensitive enough to demonstrate potential effects. At this point, one major experimental problem need to be put forward. A valid test of the question whether conceptual system knowledge promotes long term skill retention, requires adequate understanding of the explanations, and secondly, that this knowledge is retained during the non-practice interval. Unfortunately, the learning phase did not include a test of system comprehension, so it is unclear whether subjects fully understood the explanations. Even if they had acquired a certain level of understanding, this knowledge has dissolved over the four-week retention interval, as indicated by the interview, showing that all subjects had a very superficial, and often incorrect, understanding of the system's goal and principles. Thus, the efforts to attain groups differing in the nature and level of system and task knowledge has failed. In order to further explore the effects of different types of system and task knowledge requires an instructional method achieving thorough conceptual understanding in its learners. Furthermore, the experimental procedure should include a check to insure that subjects, at the end of the learning phase, have successfully acquired the knowledge and can use this knowledge to infer task procedures. Such an study is currently carried out.

REFERENCES

Catrambone, R., 1995. Following instructions: effects of principles and examples. *Journal of Experimental Psychology: Applied*, *1* (3), 227-244.

Christina, R.W., and Bjork, R.A., 1991. Optimizing Long-Term Retention and Transfer, *In:* D. Druckman, and R.A. Bjork, eds. *In the Mind's Eye: Enhancing Human Performance*. Washington, D.C.: National Academy Press, 23-56.

Dixon, P., and Gabrys, G., 1991. Learning to Operate Complex Devices: Effects of Conceptual and Operational Similarity. *Human Factors*, 33 (1), 103-120.

Johnson, S.L., 1981. Effect of Training Device on Retention and Transfer of a Procedural Task. *Human Factors*, 23 (3), 257-272.

Kieras, D., and Bovair, S., 1984. The Role of a Mental Model in Learning to Operate a Device. *Cognitive Science*, 8, 255- 273.

Kieras, D.E., 1990, The Role of Cognitive Simulation Models in the Development of Advanced Training and Testing Systems, *in:* N. Frederiksen, R. Glaser, A. Lesgold, and others, eds. *Diagnostic Monitoring of Skill and Knowledge Acquisition*. Hillsdale, NJ: Lawrence Erlbaum Associates, 51-73.

Konoske, P.J., and Ellis, J.A., 1986. *Cognitive Factors in Learning and Retention of Procedural Tasks*. San Diego, CA: Navy Research and Development Center.

Mark, M.A., and Greer, J.E., 1995. The VCR Tutor: Effective Instruction for Device Operation. *Journal of the Learning Sciences*, 4, (2), 209-246.

Smith, E.E., and Goodman, L., 1984. Understanding Instructions: The Role of an Explanatory Schema. *Cognition and Instruction*, 1, 359-396.

Stevens, A., and Steinberg, C., 1981. *Project Steamer: Taxonomy for Generating Exlanations of How to Operate Complex Physical Devices*. San Diego, CA: Navy Personnel Research and Development Center.