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Iowa State University

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Differential effects of high and low cognitive load instructional methods on recall and transfer of procedural knowledge

Sugrue, Brenda Mary, Ph.D.

Iowa State University, 1989

Differential effects of high and low

cognitive load instructional methods on recall

and transfer of procedural knowledge

by

Brenda Mary Sugrue

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1. INTRODUCTION

1.1. Background and Educational Significance

The distinction between declarative and procedural knowledge has become the basis for recent cognitive theories of how knowledge is acquired, stored in memory, retrieved, and used. Declarative knowledge is "knowledge that" (Rumelhart & Norman, 1981, p. 338) or knowledge about something; it can be in the form of facts, concepts or principles (Merrill, 1983). It is postulated that declarative knowledge is organized in memory in a hierarchical network and is operated upon by general, content-free procedures to generate task-specific procedures which allow us to interact with our external environment. Procedural knowledge is "knowledge how" (Rumelhart & Norman, 1981); it is the kind of knowledge that lets us perform actions and make decisions. Most procedural knowledge is specialized and context-dependent and, once acquired, can be used in an unconscious, automatic fashion. However, we also have more general "metacognitive" procedures such as planning, monitoring and connecting skills, which are less easy to learn (Corno & Mandinach, 1983). In the literature, metacognition is gradually replacing the more general, and less measurable and modifiable, constructs of intelligence or aptitude (Forrest-Pressley, McKinnon, & Waller, 1985). Since it is a theory of learning which directs the design of instruction, and since the dominant theory of learning has until recently been behavioral theory, the instructional method adopted for procedural tasks in most education and training settings has generally been behavioral, that is, some form of demonstration followed by

imitative practice (Romiszowski, 1981). Such instruction promotes reproduction of procedures in situations similar to the instructional context, but does not prepare most learners to transfer the knowledge acquired to new situations requiring the adaptation, application, or extension of the procedure (Bransford, Nitsch, & Franks, 1977; Clark & Voogel, 1985; Royer, 1979). There has always been a central concern in education and training that the skills or procedures learned should be applicable in settings beyond those in which initial learning took place. However, effective instructional methods for achieving that goal have been scarce. The failure of all but the brightest students to transfer both declarative and procedural knowledge has been consistently documented (Bruner, 1966; Clark & Voogel, 1985; Cormier & Hagman, 1987; Royer, 1979).

Transfer of learning ceased to be an area of research in the 1960s and 1970s because behavioral psychologists believed that the theory of "identical elements" (Thorndike, 1932) explained any transfer outcomes that the behaviorist theory of learning supported. The identical elements theory suggested that transfer occurred when there were perceptual similarities between learning and application tasks or environments; the greater the number of shared elements in learning and transfer tasks, the greater the likelihood of transfer. In the 1980s, the demands of education and training have gone far beyond that very limited transfer outcome. Increasingly complex and changing subject-matter and jobs require instructional systems that will lead to long-term retention and farther transfer (Cormier & Hagman, 1987).

Methods of instruction that aim to induce the kind of cognitive processing that results in the storage of more

integrated and transferrable procedural knowledge have been suggested and some cognitive instructional methods have already been tested with positive results. Examples of successful cognitive instructional methods include advance organizers (Ausubel, 1968), models and simulations (Mayer, 1975), and analogies (Gick & Holyoak, 1980). However, recent cognitive theories of learning from instruction suggest that the effects of instructional methods (behavioral or cognitive) are not absolute.

Acquisition processes and performance outcomes result from the interaction of instructional method with (a) learner characteristics (particularly aptitudes, prior knowledge, and motivation) and (b) learning task characteristics (procedural or declarative). The need for experimental research to explore the interactions among type of task, learner aptitude, and instructional method, and their effects on different learning outcomes, especially different levels of transfer, has been repeatedly noted (Clark & Voogel, 1985; Snow & Lohman, 1984; Tobias, 1987). Research should focus on the mediating cognitive processes engaged by the different instructional methods (Tobias, 1987). The goal of such research should be the construction of an empirically supported theory which would guide more accurate prescription of instructional methods for particular kinds of learners and particular kinds of performance/transfer goals in relation to particular kinds of tasks.

Recent reinterpretations of the findings of aptitude-treatment interaction (ATI) research (Clark, 1989; Snow & Lohman, 1984), in light of cognitive theories of learning, have led to the conclusion that fluid aptitude is a critical variable which interacts with instructional method to

produce different transfer outcomes. Fluid aptitude is
defined as the ability to adapt existing knowledge to solve
novel problems. Fluid aptitude is the essence of general
ability and therefore of the more precise construct of
metacognition (Snow & Lohman, 1984). The critical element
of instruction that interacts with fluid aptitude is the
completeness of the support for cognitive processing that is
embedded in instruction. The lower the burden of cognitive
processing placed on the learner, i.e., the more instruction
compensates for deficiencies in fluid aptitude, the higher
the level of transfer achieved by learners deficient in
fluid aptitude. However, instructional methods that
compensate for such deficiencies, often called low cognitive
load instructional methods (Cronbach & Snow, 1977), seem to
depress the transfer performance of learners who are not
deficient in fluid aptitude (Clark, 1989).

Many aspects of the studies on which the above
conclusion were based may be criticized. For example, none
of the studies employed treatments which deliberately varied
the "completeness" of the support for cognitive processing;
treatments have varied from note-taking to individually
prescribed instruction (IPI). Many of the studies were in
task domains where the prior knowledge of learners in
relation to the learning task was not controlled, for
example, mathematics or computer programming. Previous ATI
studies have not differentiated between declarative and
procedural knowledge. Neither have they measured a variety
of outcomes following the same instructional methods; such
gross outcome measures as "achievement" are not helpful in
identifying the cognitive processing effects of different
treatments. No study in this area has taken advantage of
the interactive capabilities of the computer for providing

cognitive processing support.

To improve on the design and methodology of previous ATI studies, the study reported in this dissertation did the following:

1. focused on the learning of procedures;

2. employed a learning task which would not be affected by prior knowledge;

3. designed treatments that differed only in the degree of external support for cognitive processing provided;

4. used the computer as a means of providing instruction that included cognitive processing support, and as a means of recording comprehensive acquisition and performance data;

5. measured a variety of outcomes, including two levels of transfer; and

6. interpreted the findings in relation to cognitive learning theory.

1.2. Statement of The Problem

The problem addressed in this dissertation is that of identifying the elements of instructional methods that affect cognitive processing and promote learning in some students while, at the same time, inhibiting the learning of others. In order to improve the transfer of procedural knowledge, there is a particular need for more accurate description and prescription of the optimum levels of support for cognitive processing for learners with different levels of fluid aptitude.

1.3. Purpose of the Study

The purpose of this study was to investigate the relative effectiveness of two different instructional methods, one providing more support for cognitive processing than the other, on the acquisition, immediate and delayed recall, and transfer of procedural knowledge. The mediating effect of learners' fluid aptitude (Gf) was examined. An attempt was made to identify the type of cognitive processing induced by the instructional methods during acquisition, recall, and transfer of procedures.

1.4. Research Questions

The following research questions are transformed into hypotheses at the end of Chapter 2. A rational for those hypotheses is developed in Chapter 2.

1. Which instructional method leads to best immediate recall of procedures?
2. Which instructional method leads to best delayed recall of procedures?
3. Which instructional method leads to best near transfer of procedures?
4. Which instructional method leads to best farther transfer of procedures?
5. Does level of fluid aptitude interact significantly with instructional method to produce different levels of recall or transfer?

1.5. Assumptions

1. Fluid aptitude (Gf) is "the essence of G [general ability] because it reflects response to the demand for flexible adaptation in the face of complexity both within and between tasks" (Snow & Lohman, 1984, p. 360). No assumptions are made regarding the origins (genetic or environmental) of fluid aptitude; this dissertation is concerned with the influence of learners' fluid aptitude AT THE TIME OF INSTRUCTION on what task-related knowledge is learned and what level of transfer is achieved after the instruction. Possible changes in more task-independent skills or aptitudes are neither hypothesized nor measured.

2. Prior knowledge is not a variable related to the task used in this study.

3. The effects of particular learner characteristics can be studied in isolation from others, e.g., the effect of fluid aptitude can be studied without reference to motivation.

4. The "cognitive load" of an instructional treatment is a continuous variable. While it is possible to isolate, describe, and design one method which provides more explicit support for cognitive processing than does another, and to assign the label "high-load" to one and "low-load" to the other, such labelling is largely arbitrary. However, for the purposes of this dissertation, it is assumed that there is a distinct difference in the amount of support for cognitive processing provided by the two instructional methods employed. The treatment that provided more support was labelled low-load and the treatment that provided less

support was labelled high-load.

5. The type of knowledge necessary to complete the tasks in this study is representative of that required to accomplish a variety of tasks which involve recall or application of a previously learned procedure.

6. All procedural knowledge begins as declarative knowledge about the task and the operations that can be performed to complete it.

9. The aptitude measure employed in this study is reliable and valid. .

1.6. Limitations

1. Size of sample.
2. Sample consisted of volunteers.
2. Nature of the task: laboratory, artificial, complex, not related to the real world.
3. Range of general aptitude in sample: college students are a more select group than a normal population of learners.
4. Amount of instruction: limited instruction over a short period of time.
5. Number of items in each performance test.

1.7 Definition of Terms

1. Knowledge: What is stored in memory as a result of the interaction of human mental processes and experience with the external environment.
2. Procedural Knowledge: The type of knowledge that constitutes being able to carry out a set of operations to transform an object or situation from a given state

to a goal state.

3. Acquisition Processes: Processes by which knowledge is encoded and transformed into usable procedures.

4. Immediate Recall: Reproduction of procedures, on which instruction has been provided, immediately after the required amount of practice has been completed.

5. Delayed Recall: Reproduction of procedures, on which instruction has been provided, one month following cessation of training, without intervening practice.

6. Transfer: The use of prior knowledge in the acquisition of new knowledge and the application of old knowledge in new contexts.

7. High-Load Instructional Method: An instructional method which provides a minimum of cognitive processing support for the learning of the procedures, placing a high information processing burden on the learners themselves.

8. Low-load Instructional Method: An instructional method which provides a maximum of cognitive processing support for the learning of the procedures, forcing the learners to actively process the information in a manner which characterizes expertise in relation to the task.

9. Fluid Aptitude: Aptitude for adaptation of existing knowledge to novel tasks and problems.

10. Algorithm: A procedure which, if executed, guarantees solution of a particular problem.

11. Heuristic: A general problem solving procedure which, if executed, might lead to solution of a particular problem.

1.8. Summary

Recent re-examinations of the findings of ATI research have used cognitive theories of learning to identify and propose explanations for elements of instructional treatments which interact which specific learner characteristics. Of particular interest are treatments which seem to promote learning and transfer among learners with low aptitude while, at the same time, interfering with the learning of learners with high aptitude. This study aimed to identify the precise nature of the interaction between the fluid aptitude of learners and the level of support for cognitive processing provided by instruction on procedural tasks. The computer offered an ideal environment for providing the kind of interactivity required for higher levels of support for cognitive processing. Unlike most previous studies in the area, a variety of outcome measures were employed, each requiring different levels of transfer of the procedures learned.

2. THEORETICAL ORIENTATION

2.1. Introduction

This study focuses on the relative effectiveness of two methods of instruction on the acquisition, immediate and delayed recall, and transfer of procedural knowledge. Fluid aptitude is treated as the critical moderator variable. Cognitive processing and consequent knowledge structures in memory are regarded as the critical intervening variables.

This chapter reviews pertinent theoretical and empirical literature that relates to the dependent, independent, moderator, and intervening variables in the study, building a rational for the theoretical hypotheses which are stated at the end of the chapter.

2.2. Dependent Variables

2.2.1. Acquisition of procedural knowledge

2.2.1.1. Behaviorist view of acquisition   Shuell (1986) summarizes the distinctions between behaviorist and cognitive conceptions of learning. Behaviorist conceptions of learning focus on behavior and changes in behavior without reference to either the mental processes that underlie such changes or the prior knowledge of the learner. An enduring change in an individual's ability to perform some task, as a result of reinforcement of particular responses to the stimulus situation, constitutes learning. Consequently, behaviorists are concerned with changing the environment in order to influence learning and performance. In order to facilitate acquisition of a procedure, learners

would be shown the correct response or set of responses to a
particular stimulus, that is, the state of the task to which
the procedure should be applied. Little support would be
provided for appropriate cognitive processing. With
sufficient practice, all learners should be able to
reproduce that procedure subsequently whenever the same
stimulus is encountered.

The behaviorist movement began in the second decade of
the twentieth century and dominated American psychology
until the late 1950s (Gardner, 1985). Educational research
and practice was just one of the activities in society which
became focused on observable behavior and modification of
the external environment without reference to what might be
occurring in the inner environment of the human mind.

2.2.1.2. Cognitive view of acquisition   Cognitive

conceptions of learning focus on "the acquisition of
knowledge and knowledge structures rather than on behavior
per se" (Shuell, 1986, p. 413); behavior is a by-product of
learning and reflects the nature and extent of stored
knowledge. Feedback on the appropriateness of one's
existing knowledge in relation to a particular task or
situation, rather than reinforcement for imitation of an
observed correct response, is what influences learning.
Cognitivists focus on changing the learner's knowledge
acquisition processes and the manner in which knowledge is
structured in memory.

While the current "cognitive revolution" (Gardner,
1985) in psychology began in the late 1950s, the roots of
that revolution lie in the late 1800s and early 1900s,
particularly in the work of Wundt, Bartlett, James, and the
Gestalt psychologists (Gardner, 1985). A minority of

psychologists, such as Piaget, kept the cognitive tradition alive during the 1930s and 40s. However, it was not until the late 1950s that cognitive psychology began to replace the behaviorist paradigm (Gardner, 1985). The work of Miller (1956) and Bruner (1966, 1973) heralded the current wave of cognitive theories of learning.

The distinguishing feature of all cognitive theories of learning is their view of acquisition of knowledge as a two-stage process which could be called reception and transformation, transformation referring to the integration of new knowledge with knowledge already stored in memory. In order to facilitate the acquisition of a procedure, learning situations would be devised which would allow each learner to integrate the new procedure into his/her unique store of previous knowledge. Instruction would provide support for the integration of new knowledge with old. The greater the extent of transformation of existing memory structures to accommodate new information, the greater the subsequent ability to transfer the newly-learned procedure in novel situations.

Bruner (1966) viewed learning as the discovery of regularities and structure in knowledge and the construction of connected, economical, generic, and powerful cognitive structures to represent that knowledge in memory. Bruner's theory of learning was vague, did not distinguish between types of knowledge, did not detail the nature of the cognitive structures in which knowledge was stored, and did not lend itself to empirical testing. However, his equation of learning with transfer and his acknowledgement of the important roles played by goals, theory generation, and knowledge of results, i.e, feedback, in the process of learning, continue to be echoed in the more explicit,

comprehensive, and testable theories of learning that have recently emerged (Anderson, 1983; Royer, 1986; Voss, 1978).

Royer (1986) suggests that, for a learning theory to provide a comprehensive perspective on the constructive process of learning, it must

1.   specify the nature and the organization of the material that is represented in memory;

2.   specify how some subset of long-term memory becomes active when processing information;

3.   specify how incoming information interacts with knowledge already in working memory during the process of constructing an interpretation of the incoming information; and

4.   specify how the newly interpreted information becomes part of long-term memory.

Anderson's theory of learning (1982, 1983) may be regarded as "the most explicit and comprehensive of current cognitive theories of learning" (Shuell, 1986, p. 422). Anderson's theory will be described here in detail and used to interpret the findings of this study. Anderson's theory is based on the assumption that there is only one basic mode of cognition (i.e., one basic learning mechanism) which can account for the acquisition and development of all skills, from language to problem solving. Anderson (1983) proposes the existence of three distinct memories:

1.   declarative memory, in which declarative knowledge is stored in a propositional network representing the relationships among facts and concepts;

2.   production memory, in which procedural knowledge is stored as a set of productions or if-then rules. These rules can either operate on information stored in declarative memory or can be applied directly when the

goal or subgoal of a task situation matches the goal of
an already stored production. A production specifies
both the circumstances under which a particular action
should be carried out and the details of how to carry
out the action. Since all actions are executed in the
pursuit of goals, all cognitive processing is viewed by
Anderson (as, indeed, it was by Bruner) as a
goal-directed activity;

3.   working memory, through which declarative and
procedural knowledge interact with each other and with
the environment. In Anderson's model, the processes
which link these three memories are encoding, storage,
retrieval, production application which results from
matching and execution, and performance. Figure 2.1,
reproduced from Anderson (1983, p. 19) indicates the
major structural components of memory and the processes
which operate on them.
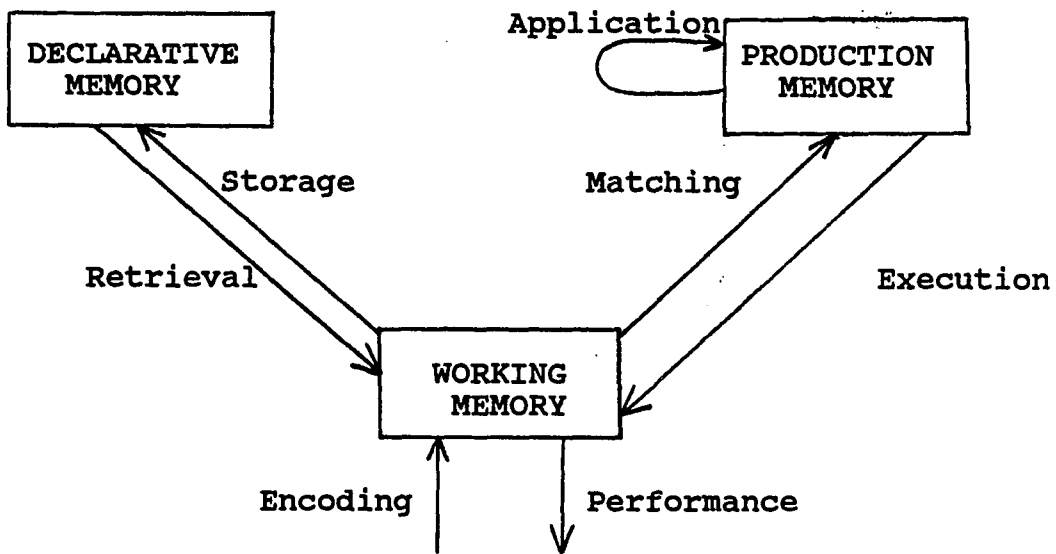
Figure 2.1. Anderson's (1983) model of memory structures
            and operations

In Anderson's theory, the acquisition of procedural knowledge involves three stages: interpretation, compilation, and tuning. Each of these will now be described.

2.2.1.2.1. Interpretation of declarative knowledge
For procedural knowledge to be acquired, task-specific declarative knowledge must be encoded from the external environment, or retrieved from declarative memory, into working memory. The declarative information might be in the form of direct instructions on how to complete a task or solve a problem, or might consist of less complete directions related to the task. Task-independent productions use these declarative representations to produce the desired behavior or an approximation of the desired behavior. If the declarative information is in the form of direct instructions, then a person may just execute them one by one.

If the information is less complete, then it may be treated as data for general problem solving procedures (e.g., means-ends analysis, working backwards) which produce coherent, domain-appropriate behavior. It is assumed that the learner will have encoded the goal structure of the task itself declaratively. The consequences of the action generated by the interpretive procedure will reveal errors and "misunderstandings" (Anderson, 1982, p. 379) in the current procedural interpretation of the task, creating the "opportunity for new learning" (Anderson, 1982, p. 379). Anderson suggests that in the case of such errors/misunderstandings, additional declarative information should be given to the learner. Alternatively, incomplete declarative information can be interpreted by analogy with

procedures that apply to similar tasks.

2.2.1.2.1. Compilation of productions

To avoid the necessity for repeated and potentially errorful interpretation of declarative information for every execution of an action, task-specific procedures are compiled and stored as more or less error-free productions in production memory, to be applied directly when appropriate task situations are encountered in the environment. Two subprocesses, composition and proceduralization, are involved in knowledge compilation. Composition takes a sequence of productions and collapses them into a single "macroproduction" (Anderson, 1983, p. 235). Proceduralization builds versions of productions that no longer require access to declarative information, the essential products of retrieval of declarative information being built into the productions. Both composition and proceduralization speed up the application of procedures found to be appropriate for a particular task. Proceduralization decreases the demands placed on working memory and is similar to Shiffrin and Schneider's (1977) concept of automatization of a skill. To prevent the compilation of erroneous productions, compilation is a gradual process and occurs as a result of practice.

2.2.1.2.3. Tuning of productions

According to Anderson (1983), "Much learning still goes on after a skill has been compiled into a task specific procedure, and this learning cannot just be attributed to further speedup through more composition" (p. 241). The final stage of learning leads to greater selectivity in the search for the best procedure to achieve a particular goal or subgoal in a

task situation, and is greatly facilitated by the goal structure of productions.

Anderson proposes a set of three mechanisms involved in tuning: generalization, discrimination, and strengthening. Generalization is the process by which production rules become broader in their range of applicability. This process facilitates the transfer of procedures to novel situations and involves comparing two or more productions and extracting what they have in common to form a more powerful, general rule. This is similar to Bruner's (1973) notion of constructing generic, economical representations of knowledge to facilitate transfer. Anderson suggests that the process of generalization is facilitated by the teaching of the same components in two different procedures.

Discrimination is the process by which production rules become narrower in their range of applicability. It requires the experiencing of instances of the correct and incorrect application of the production, so that the variables in situations where the production is successful can be compared with the variables in situations where it is not successful. Feedback, either implicit or explicit, on the correctness of the procedure applied, is a prerequisite for discrimination.

Strengthening is the process by which better productions are strengthened and poorer productions are weakened. Because generalization and discrimination are inductive processes (i.e., they involve extracting the applicability of a production from features of the instances where a production succeeds or fails), they will sometimes err and produce incorrect productions, overgeneralizations, and useless discriminations. A strength mechanism is needed to improve the accuracy and speed of a procedure by

increasing the strength of appropriate applications and lessening the strength of incorrect applications of a procedure. Strength of a production is a function of practice and feedback, and determines the amount of activation a production receives in competition with other productions during matching of task information with production conditions/goals.

Anderson's theory predicts that new procedures are learned by observing how well interpretive procedures match the goal of the new task and modifying procedures until they are task-specific. Hayes-Roth, Klahr, and Mostow (1981) also view knowledge acquisition as an iterative process of action based on the match between one's declarative representation of a task and rules or schemata that already exist in memory, and transformation of rules, in the light of feedback, to achieve the goal of the task. For Hayes-Roth et al., "violated expectations are the triggering events for learning" (1981, p. 243). Papert (1980) adheres to a similar view, as, indeed, did Dewey (1938) when he advocated the scientific method as the only authentic means of learning from experience.

2.2.1.3. Operational definitions of acquisition processes

If one postulates a theory, either behaviorist or cognitive, of how procedural knowledge is acquired, then one must find some means of assessing if, and to what extent, that theory is valid. From the behaviorist point of view, if a learner can reproduce the correct procedure in the correct stimulus environment, then the learner has acquired the procedure.

From the cognitive point of view, it is the cognitive processes that operate during the acquisition, storage and

retrieval of procedures that are of interest. A variety of methods have been developed recently for measuring those cognitive processes. Some of those methods focus on observation of behavior during learning from which inferences about internal processing can be drawn. Examples of such methods include the use of computer-recorded protocols to measure individual differences in processing activity during computer-based instruction (Snow, 1980). Hooper (1986) related the computer-recorded protocols of individual learners, as they carried out activities on a manipulative model of computer memory, to their subsequent solutions of programming problems in order to identify information processing and storage differences. White (1984) used a combination of diagrams and notes made by learners during solution of problems, computer-recorder protocols of learner inputs while playing games on Newton's laws of motion, tape-recorded interviews, and extensive notes made by the experimenter during the experimental sessions to measure learners' reasoning processes before, during and after exposure to the games. Gray (1983) used teachback protocols, contents of learners' notes, and worksheet activities to measure the amount and kind of cognitive activity in which learners of different abilities engaged. Gray was able to derive indices of learners' effectiveness in selectivity and connecting of new information to old information.

Other methods used to measure cognitive processing during learning and performance include verbal reports obtained from learners either during or after a learning or performance activity. For example, Snow (1980) employed a combination of verbal reports and eye-movement records to develop process descriptions of performance on aptitude

tests. Larkin and Rainard (1984) documented, analyzed, and built and tested computer models of, the cognitive processes identified from the think-aloud protocols of learners during the solution of physics and chemistry problems. Corno and Mandinach (1983) refer to the problems of devising valid and reliable indices of cognitive functioning from verbal protocols and other intensive data collection methods.

Performance on transfer tasks can provide indications of the cognitive processes engaged during initial acquisition of knowledge (Royer, 1986). Kamouri, Kamouri, and Smith (1986) employed a combination of rating forms, written retrospective reports relating to instructional and transfer tasks, predictions about the requirements of transfer tasks, and performance on analogous and disanalogous transfer tasks to assess the extent of "schema induction" and subsequent analogical reasoning facilitated by two different instructional methods.

Finally, detailed task analysis focusing on the information processing demands of a learning task can aid the analysis of the behavior and inference of cognitive processing of learners during the acquisition, recall and transfer of procedures.

2.2.2. Immediate and delayed recall

The level of acquisition of procedural knowledge can be inferred from performance on tests after learning. Reproduction of the procedure after completion of instruction will indicate that the procedure has at least been stored in production memory and can be retrieved in a stimulus situation similar to that in which instruction took place. The speed of recall may vary, depending on the

amount of repetitive practice that occurred to proceduralize or automatize the procedure (Anderson, 1983). However, the mere reproduction of a procedure shortly after instruction does not mean that the knowledge was deeply and constructively processed during acquisition.

Many procedures are learned which must be "retained" for long periods of time until a situation arises which warrants their execution. Therefore, procedural knowledge must be acquired in a manner that facilitates its delayed recall or reproduction. According to Craik and Lockhart (1972), "differently encoded representations apparently persist for different lengths of time" (p. 675). Rates of forgetting seem to be a function of the type and depth of initial processing. It may be that the compilation and strengthening of ready-made procedures results in less retainable procedures than procedures that were constructed through a process of interpretation of incomplete declarative information via either analogical or general problem solving procedures. In the latter case, if parts of a procedure are "forgotten", then it should be possible to reconstruct them by the reactivation and interpretation of declarative knowledge.

As well as being a better measure of initial processing of information, it seems that delayed recall tests are better measures of the moderating influence of learner characteristics, such as general ability, on the effects of instructional method on acquisition processes than are tests of immediate recall, which tend to remove such influences. (Cronbach & Snow, 1977).

2.2.3. Transfer

Royer (1979) defines transfer as "the extent to which the learning of an instructional event contributes to or detracts from subsequent problem solving or the learning of subsequent instructional events" (p. 53). The cognitive view of learning as the interpretation and integration of new information in terms of prior knowledge in memory has led many theorists to logically equate learning, or level of understanding, with transfer (Bruner, 1966; Royer, 1986; Voss, 1978). The degree to which knowledge can be used in new contexts thus becomes the operational definition of the degree to which the knowledge has been actively processed and stored in generalizable procedures. Royer (1986), taking the example of long division, explains:

> Successful completion of problems identical to or very similar to those experienced during instruction is a lesser accomplishment than solving completely new problems. Extending this idea further, it would be even more impressive if the student used his or her long division skills in situations encountered outside the classroom (p. 95).

The classical, or behaviorist, view of transfer is based on an "identical elements" theory (Royer, 1979, citing Thorndike & Woodworth, 1901). This theory suggests that transfer from one task to another only occurs when both tasks share identical elements; the greater the number of shared elements, the greater the amount of transfer. The critical step in the transfer process is thus the recognition that one task shares a set of stimulus features with another. If the recognition process does not occur, then the transfer of a previously learned response (e.g., a

procedure) cannot occur (Royer, 1979).

Such a behavioral theory of transfer describes the
conditions under which various kinds of transfer will be
evident, but does not specify the cognitive processes that
are responsible for the transfer behavior (Royer, 1979).
According to Royer (1979), "A theory of transfer, in the
true sense of a theory, would have to specify the
psychological processes that support the observable
behavior" (p. 57). Another criticism of the identical
elements model of transfer is that it only predicts transfer
in those situations where there is a clear and known
relationship between the stimulus elements of the original
and the transfer tasks.

With the development of cognitive theories of learning,
cognitive theories of transfer have also emerged, theories
which focus on the influence of prior knowledge and prior
cognitive structure on the acquisition of new knowledge and
on the application of old knowledge to novel situations.
Distinctions have been drawn between lateral and vertical
transfer (Gagne, 1965), specific and non-specific transfer
(Ellis, 1965), literal and figural transfer (Royer, 1979),
near and far transfer (Mayer, 1975), high-road and low-road
transfer (Salomon & Perkins, 1987).

Recently, Royer (1986) has proposed a two dimensional
scheme for describing various degrees of transfer and,
hence, of learning. The dimensions he uses are near-far and
literal-figural. The near-far dimension reflects the
degree to which the CONDITIONS of transfer task performance
resemble those of learning. Far transfer, in which there
are few cues available that would indicate that a particular
procedure should be used, represents a higher level of
understanding, i.e., deeper level of processing during

acquisition, than near transfer task performance. According to Royer (1986),

> The reason is that a student who performs successfully
> in far transfer situations is almost certain to be able
> to perform successfully in near transfer situations
> when both situations involve the same skill. However,
> the converse is not true. Students who can perform in
> near transfer situations may not be able to
> successfully perform a far transfer task (p. 96).

Interpreting this in terms of Anderson's (1983) theory of procedural knowledge acquisition, it appears that the processes of generalization and discrimination facilitate far transfer, while the process of strengthening facilitates near transfer.

The literal-figural dimension in Royer's scheme concerns the NATURE of the skills that are transferred. Literal transfer involves the transfer of an intact procedure or piece of knowledge. Figural transfer involves the transfer of more abstract, complex, and general knowledge or procedures. Interpreting this in terms of Anderson's (1983) theory, it seems that figural transfer would involve matching of the goals of a new task with the goals of some task-independent problem solving procedures or analogical procedures, whereas literal transfer would involve the matching of the goals of the task to existing task-specific procedures stored in production memory.

Royer (1986) combines the near-far and literal-figural dimensions in the following diagram to provide a means of categorizing transfer tasks or levels of expertise in a domain. For the assessment of attainment of different instructional goals, tasks may be selected from the appropriate quadrant(s) in Figure 2.2.

FIGURAL TRANSFER	Mastery of abstract knowledge	Expert performance
LITERAL TRANSFER	Mastery of basic skills	Generalization of basic skills

NEAR TRANSFER   FAR TRANSFER

Figure 2.2. Royer's (1986) categories of transfer

2.2.4. Summary (dependent variables)

The nature of cognitive processing during the acquisition of procedural knowledge determines the extent to which procedures learned can be recalled and transferred after instruction. A behaviorist theory of learning, ignoring prior knowledge, internal processing variables and transfer, focuses on explaining, and devising instructional methods to promote recall of procedures. A cognitive theory of learning, such as that of Anderson (1983), focuses on the cognitive mechanisms that operate during learning and that promote different levels of transfer of knowledge. Any empirical study of learning would need to examine a variety of outcomes and to infer from those outcomes, as well as from other measures of acquisition, the type of cognitive processing induced by instruction.

2.3. Independent Variables

Many variables can influence the acquisition, and subsequent recall and transfer of procedural knowledge. Instructional methods can either short-circuit, model, or activate processes involved in knowledge acquisition (Cronbach & Snow, 1977; Salomon, 1979). However, because of differences in learner and task characteristics, no instructional method can be said to have absolute effects on the learning process or on subsequent recall and transfer.

Level of general ability interacts with instructional method to produce different levels of recall and transfer (Cronbach & Snow, 1977). Prior knowledge also influences the acquisition of new knowledge (Anderson, 1982; Siegler, 1983; Voss, 1978). Metacognition (a more recent definition of general ability), which refers to knowledge about cognition and conscious regulation of cognitive processing (Loper & Murphy, 1985), has been found to be positively related to acquisition, retrieval and transfer of knowledge (Pressley, Borkowski, & O'Sullivan, 1985; Schneider, 1985). Characteristics of the task or procedure to be learned, such as complexity, also influence the acquisition of procedural knowledge (Tobias, 1987). Other variables, such as cognitive style, anxiety, and motivation also influence learning (Bandura, 1982; Tobias, 1987; Weiner, 1976).

It would be practically impossible to study simultaneously the influence of such a complex network of variables on the acquisition of procedural knowledge. Therefore, most experimental research in the area controls for some of these variables, ignores others, and focuses on those which are deemed to be most influential and most amenable to change. The two independent variables which

will be investigated in this dissertation are instructional method and fluid aptitude. The final section of this chapter focuses on those two independent variables, highlighting their main effects and interaction effect on learning processes and performance outcomes.

2.3.1. Instructional method

The main feature of a behavioral method of instruction is that it provides complete task-specific declarative and/or procedural knowledge, but no cognitive processing support to the learner in terms of facilitating the integration of new information with the learner's prior knowledge. The interpretive stage of knowledge acquisition is short-circuited; a high information processing burden is placed on the learner who must activate the interpretive stage of knowledge acquisition for him/herself in order to render the information more meaningful and transferrable. Therefore, instructional methods that do not attempt to engage active processing are often called "high-load" methods (Cronbach & Snow, 1977). The traditional lecture is a high-load method because it generally presents information to learners without any attempt to induce or monitor in individual students the kind of cognitive processing that would be necessary to reorganize and integrate the information in a meaningful way.

The main feature of cognitive methods of instruction is the provision of the cognitive processing support necessary to integrate new information with old. This is usually accompanied by incomplete information; learners compile complete procedural knowledge through actively processing the incomplete information presented. The interpretive

stage of knowledge acquisition is supported. Learning in this manner facilitates the later retrieval and use, and the transfer of procedures to novel problems (Royer, 1986). Such methods are often called "low-load" because they model, or compensate for, the kind of cognitive processing that is required to become expert in a particular task domain. Some guided discovery instructional methods, such as interacting with analogical models or simulations are low-load methods because they force learners to test their existing knowledge in relation to a task, only to find out that there are gaps in that knowledge (Hooper, 1986). The awareness of a "gap" or misunderstanding represents an opportunity for learning and the learner will actively modify his/her existing knowledge and compile it into more error-free and generalizable procedures.

Before hypotheses in relation to the differential effects of high and low-load instructional methods can be formulated, it must be acknowledged and emphasized that the effects of instructional methods on the acquisition of knowledge are by no means absolute. There is a large body of evidence from aptitude-treatment interaction studies which indicates that the effects of any instructional method are mediated by a variety of learner aptitudes (Cronbach & Snow, 1977; Snow & Lohman, 1984). Learner aptitudes, such as prior knowledge, level of general ability, and motivation interact with instructional method to produce different types of cognitive processing, knowledge structures in memory, and performance outcomes, particularly levels of transfer (Clark, 1989; Snow & Lohman, 1984; Tobias, 1987). Clark and Voogel (1985) conclude that current evidence best supports the influence of two types of learner aptitude on transfer: general ability (intelligence) and prior

knowledge (previously acquired content information), general ability being the best predictor of transfer under all task conditions. They note that "one of the most common and supportable findings in educational research is that farther transfer is achieved by students with higher general ability scores" (p. 120).

2.3.2. Fluid aptitude

In attempting to develop a theory of learning from instruction based on aptitude, Snow (1980), and Snow and Lohman (1984), adopt Cattell's (1971) differentiation between two ability or aptitude factors: fluid aptitude (Gf) and crystallized aptitude (Gc). Gc reflects the ability to retrieve and apply previously stored procedures to familiar tasks. Gf reflects fluid facility in adapting crystallized procedures to new purposes or in forming new procedures whenever previously crystallized units (i.e., compiled procedures) cannot be routinely applied. Gf seems to be the essence of general ability, because "it reflects response to the demand for flexible adaptation in the face of complexity both within and between tasks" (Snow & Lohman, 1984, p. 360).

Learners with higher Gf appear to spontaneously use analogies and construct more general procedures during learning and problem solving than do learners with low Gf (Holyoak, 1984; Resnick, 1976; Sternberg, 1985). Learners with higher Gf more actively seek to construct personally meaningful and useful declarative and procedural knowledge. They are more likely to engage in the elaborative encoding, reorganization and continuous testing of their "provisional assemblies" (Snow & Lohman, 1984, p. 370) or procedures.

Learners with lower Gf rely on simpler connections and non-semantic forms of elaboration such as maintenance rehearsal; their strategy demands more attention and memory resources and leaves stored procedures highly susceptible to interference from subsequent declarative inputs. Learners with higher levels of Gf avoid both interference and strains on resource allocation by recoding and reorganizing incoming information. It may be that the metacognitive processes employed by learners with higher Gf have themselves become virtually automatic processes.

In terms of Anderson's (1983) theory of learning, learners with higher Gf will engage in the interpretive stage of knowledge acquisition regardless of whether the instruction is designed to induce or short-circuit that process. However, it seems that instruction which provides too much support for the interpretive stage of learning inhibits or interferes with the existing strategies, of learners with higher Gf, to integrate and reorganize knowledge for themselves (Clark, 1989; Snow & Lohman, 1984). Learners with higher level of Gf do especially well under instruction that is significantly incomplete in terms of the support for cognitive processing provided, because it affords them opportunities for the spontaneous "active retrieval and adaptation of old assemblies [procedures] and, particularly, the invention of new assemblies [procedures]" (Snow & Lohman, 1984, p. 372), without imposing a strategy for doing so.

Less is known about the type of instructional conditions that best help learners with lower levels of Gf to adapt and construct new procedures. Snow and Lohman (1984) prescribe the provision of instruction that is "explicit, direct, and structured in detail so as to provide

the procedural knowledge as well as the conceptual [declarative] knowledge that such learners may not be able to provide for themselves" (p. 372). The present writer would add that such instruction should force low Gf learners to engage in the interpretive stage of knowledge acquisition; it should provide for those learners support for, or initiation of, the kind of strategies that they cannot provide for themselves. The concrete analogical models and verbalization techniques employed by Mayer (1981) are an attempt to make explicit for learners the processes that high ability learners engage in spontaneously. Mayer's findings indicate that such externalization of effective acquisition processes are most effective in promoting transfer of knowledge for learners with low general ability.

Many other studies, such as those by Dansereau et al. (1979), Gray (1983), Peterson, Janicki, and Swing (1979), and Yalow (1980), have compared the effects of high and low-load instructional methods on learners with different levels of general ability, and have obtained results similar to those of Mayer (1981). According to Snow and Lohman (1984),

It is often, though not always the case, that . . . the treatment that is mathemagenic (i.e., gives birth to learning) for one kind of learner appears to be mathemathanic [sic] (i.e., gives death to learning) for another kind of learner, and vice versa" (p. 355).

In Gray's (1983) study, three levels of an instructional method sought to provide from a minimum to a maximum of support for the particular cognitive processes of grouping, reorganizing, and elaborating the information to be learned. The results indicated that the higher the level of learning strategy support, the greater the achievement of the lower aptitude students, presumably because it forced

them to reorganize new information in a personally
meaningful manner, something that they were not capable of
doing on their own. However, with learners with higher
general aptitude (in this case Gc), the greater the degree
of compensatory support, the lower the level of overall
achievement. The highest aptitude students complained that
the intervention interfered with the strategies they
normally used. These results are echoed in studies where
measures of Gf rather than Gc were employed. The general
regression outcome looks like Figure 2.3.
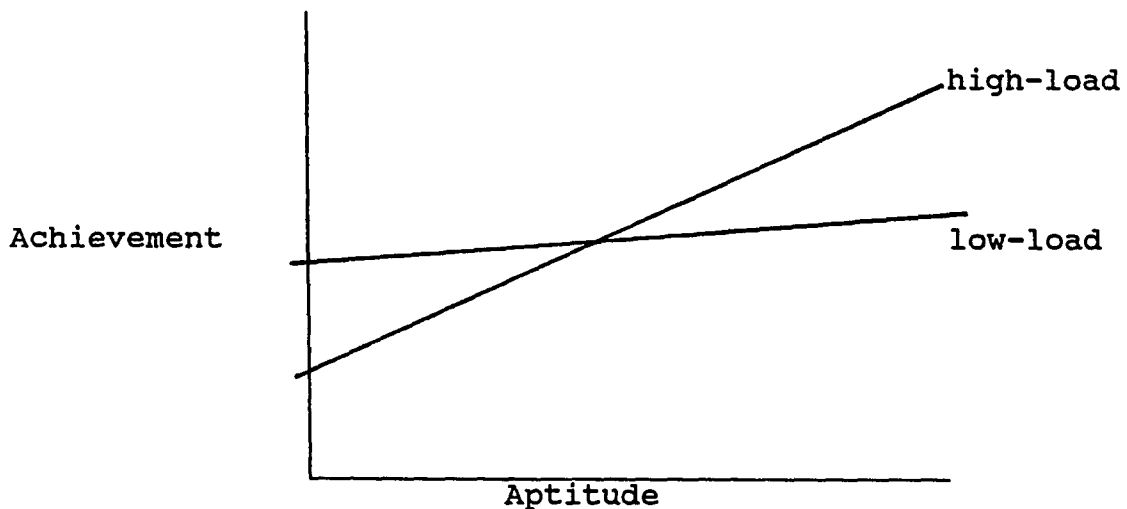
Figure 2.3. Common disordinal interaction between aptitude
and learning outcome following high and low-
load instructional methods

This pattern of disordinal interactions between general
aptitude and instructional method becomes less apparent as
the level of transfer increases, because "neither flexible
adaptation nor transfer can stretch to tasks demanding
radically different procedures" (Snow & Lohman, 1984, p.
371).

In addition to task-specific cognitive processing
support for lower ability learners, Snow and Lohman (1984)

recommend that parallel instruction on specific learning strategies should be provided. Some researchers have reported success with such direct training of learning strategies or study skills with low ability learners (Dansereau, 1978; Gray, 1983). However, Campione, Brown, and Ferrera (1982) suggest that such training does not lead to the durable use of those generic learning strategies. Derry and Murphy (1986) also argue that

> Executive learning skills cannot be trained easily or by direct instruction alone, but must be developed gradually and automated over an extended period of time. It follows that improvement of academic aptitude is not likely to result from anything less than a thoughtful, systematic curriculum that complements direct training in learning strategies, and thereby "engineers" the gradual evolution of important executive control skills (p. 1).

Instruction in all subject areas which would force individual learners to engage in an active process of construction of procedural knowledge may be more effective than training of metacognitive skills in isolation. It may be that the act of integrating new task-specific knowledge with old and reorganizing task-specific knowledge stored in memory will increase learners' tendency to do so in all areas over time. However, further ATI research with more clearly defined treatments and multiple outcome measures, including far transfer from one content domain to another, is needed to identify instructional methods that may benefit learners with low fluid aptitude in terms of transfer of learning within and between learning tasks.

2.3.3. Summary (independent variables)

Level of general ability interacts with instructional method to produce different learning outcomes. In particular, instructional methods that place a high cognitive processing burden on learners themselves are best for learners with high fluid aptitude because fluid aptitude is the ability to integrate and abstract generalizable procedural knowledge. However, such high-load methods are "mathemathantic" (i.e., kill learning) for learners who lack fluid aptitude. Learners with low levels of fluid aptitude need instructional methods which are more complete in that they force learners to engage in the kind of processing that is necessary for the creation, storage, retrieval and use of generalizable procedures. Such "low-load" methods take the burden of cognitive processing out of the hands of the learner and build the necessary support into the instructional activities themselves. However, often these low-load methods interfere with the metacognitive strategies that learners with high fluid aptitude employ spontaneously at the interpretive stage of learning and again at the point where transfer of learned procedures is required. Further research is needed to identify and refine the necessary elements of instructional methods that are "mathemagenic" (i.e., promote learning) for learners with particular aptitudes in relation to particular types of tasks and for particular levels of transfer.

2.4. Theoretical Hypotheses

1. High-load instruction takes less time and promotes less active processing than does low-load instruction.

2. High-load instruction leads to better immediate recall of procedures than does low-load instruction.

3. Low-load instruction leads to better delayed recall of procedures than does high-load instruction.

4. Low-load instruction leads to better transfer of procedures to novel task situations than does high load instruction.

5. Level of fluid aptitude interacts significantly with instructional method to produce a steeper regression slope for high-load instructional method than for low-load instructional method, when the dependent variable is delayed recall or transfer. Low-load instruction may compensate for deficits in the aptitude that is positively correlated with ability to learn and to transfer procedural knowledge.

3. METHODOLOGY

3.1. Introduction

.The methodology described in this chapter evolved from a pilot study conducted with 32 subjects in November 1987. The pilot study determined the amount of instruction, practice and tests to include in the main study. The pilot study also led to a refinement of differences between the two instructional programs and the type of data recorded.

This chapter describes the research design, the sample, the task for which two instructional programs were developed, the components of expertise in the task, the instructional programs themselves (high-load and low-load), the aptitude measure employed, the nature of the data collected, the methods of analysis used, and the empirical hypotheses tested.

The Iowa State University Committee on the Use of Human Subjects in Research reviewed this study and concluded that the rights and welfare of the human subjects were adequately protected, that risks were outweighed by the potential benefits and expected value of the knowledge sought, that confidentiality of data was assured and that informed consent was obtained by appropriate procedures.

3.2. Research Design

A post-test only, two-group, single factor design was used. The main factor of interest was instructional method, with two levels, high-load and low-load. Subjects were matched on level of general ability and each matched pair was randomly assigned to treatment groups.

3.3. Subjects

At the beginning of the experiment, the sample consisted of 95 volunteers from the total first-year group of 178 students at Thomond College of Education. Thomond College offers a four-year degree program in education for future teachers of physical education, wood and building technology, metal and engineering technology, and general and rural science; students major in one of these subject areas. Approximately 25% of students are "mature students" who dropped out of formal education to pursue a career in a trade area and who have returned to college to obtain a degree to teach either wood and building technology or metal and engineering technology in secondary and technical schools in Ireland. All of the students are selected at entry, based on results of either the Leaving Certificate examination (the state examination at the end of secondary school) or, in the case of the mature students, aptitude tests.

The original 95 subjects in the sample were matched on scores on Raven's Progressive Matrices test (a measure of general ability). Members of each matched pair were randomly assigned to either of two treatment groups (high load and low load). Eighty subjects (40 in each treatment group) completed all stages of the experiment. The groups remained equivalent on the general ability measure on which they were matched (F=.0699, df=1,78, p=.729). Twenty-one subjects were female and 59 were male. The age of the subjects ranged from 17.25 to 37.0 years, with a mean of 20.1 and a standard deviation of 2.9 years.

3.4. Independent Variables: Operational Definitions

3.4.1. Instructional method

3.4.1.1. The task: Challenger   In order to minimize
the effects of prior knowledge, a "meaningless" or
"laboratory" type task was selected for the purposes of the
study. The task has two main features: patterns (512
possible) and operations (3 possible).

3.4.1.1.1. Representation of the task and its
operations   Challenger is a computer-based
two-dimensional "puzzle" or set of tasks consisting of a 3x3
square matrix of cells, each cell being either green or
white. The goal of the task is to change the pattern from
an arbitrary arrangement of green and white cells to a
matrix consisting of a single white cell surrounded by eight
green cells as in Figure 3.1.
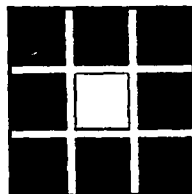
Figure 3.1. Challenger goal state

    The colors of a subset of the cells in the matrix can
be changed by placing the cursor (using the arrow keys) on a
GREEN cell and pressing <RETURN>. The cell on which the
cursor is placed changes to white and some or all of the
cells adjacent to that cell also change color. Due to the
symmetrical nature of the matrix, three distinct moves are

possible:

1. if the cursor is on a corner cell, then that corner cell and the three cells surrounding it change color;

2. if the cursor is on the middle cell of any side, then all three cells on that side change color;

3. if the cursor is on the center cell, then that cell and the middle cell on each side of the matrix change color. Figure 3.2 illustrates the three types of moves.

corner move	side move	center move
* C G	C * C	G C W
C C G	G G W	C * C
W G W	G G G	W C W

G = green cell.

W = white cell.

* = where cursor is placed.

* and C = cells that change color.

Figure 3.2. Possible moves in Challenger

For all except one of the possible 512 initial patterns of the task, there is a shortest sequence of moves which leads to the goal state. In the case where all the cells are white, there is no way to reach the goal. Once the goal state is reached, no further move is necessary.

3.4.1.1.2. Procedural knowledge of Challenger

Anderson (1983) has proposed that all human procedural knowledge begins as declarative knowledge which is either sufficiently complete to be compiled directly into

task-specific procedures or incomplete, thus requiring
interpretation via existing procedural knowledge and
transformation into task-specific procedures before
compilation. Compilation involves the automatization of
task-specific procedures and the creation of
macroproductions which carry out the operations of two or
more productions. Practice in applying particular
procedures can result in the abstraction of more general and
transferrable procedures, the strengthening of successful
productions, and more accurate selection of productions
appropriate for particular situations. Thus, the procedural
knowledge stored by humans can be task-specific and/or task-
independent, some procedures being more recallable and some
more transferrable than others.

The initial declarative knowledge required for the
Challenger task would be knowledge of the structure and
purpose of the task, knowledge of the goal state, and
knowledge of the three types of moves and their resultant
color changes. Task specific procedures that need to be
learned would be of the form:
IF pattern X is desired
        and the current pattern is Y,
                THEN make move A on cell B.

A compiled procedure would involve the connecting of
two or more moves in a sequence to get from an initial
pattern to a goal pattern. The abstraction of more general
rules would be possible due to the symmetrical nature of the
task, some patterns being rotations or translations of
others. For example, the patterns in Figure 3.3 are
rotations of the same pattern where two corner cells on one
side are green, the middle cell of the opposite side is
green and the center cell is green.

```
W W G        W G W        G W W        G W G

  G G W      W G W        W G G        W G W

W W G        G W G        G W W        W G W
```

G = green cell.

W = white cell.

Figure 3.3. Symmetrical nature of Challenger

A "side" move on the side with only one green cell will change each of these patterns to the pattern in Figure 3.4, which is only one move away from the goal state:

```
G W G

W G W

G W G
```

G = green cell.

W = white cell.

Figure 3.4. Pattern one move from Challenger goal

As one works backwards from the goal, the number of possible patterns from which a pattern nearer the goal can be reached in one move increases. The more one can recognize rotations of familiar patterns and apply the appropriate move, the greater one's chances of success in a minimum number of moves.

The sequence of moves in Figure 3.5 represents an optimum set of moves to reach the goal from a pattern six moves removed from the goal.

```
W W *           W G W           W * W           G W G

G G G  --->  G W W  --->  G W W  --->  G W W

W G G           W * G           G W W           * W W


        G W G                   G W G                   G G G

--->  W G W        --->  W * W        --->  G W G

        W * W                   G W G                   G G G
```
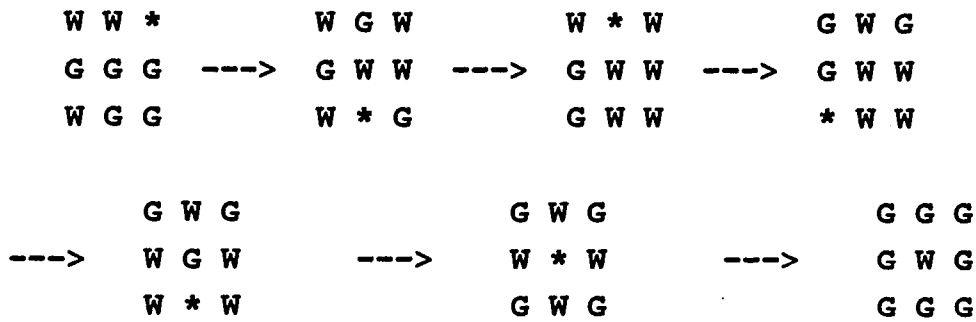
G = green cell.
W. = white cell.
* = cursor position for move.

Figure 3.5. Moves in one Challenger solution path

Performance of the successful strategy shown in Figure
3.5 could be the result of the application of a compiled
specific production system leading from the initial pattern
to the goal pattern or it could be the result of applying a
more general or abstracted production system. If the
initial pattern were unfamiliar, then more general heuristic
procedures would be called for, based on anticipation of the
outcome of a move or a sequence of two moves; the goal in
this case would be to reach a familiar pattern for which a
production had already been compiled.

3.4.1.1.3. Components of expertise in solving
Challenger   An expert solver of the Challenger task would
need to have acquired, stored and be capable of retrieving
procedures (either specific or general) for solution from
all possible initial patterns of Challenger. It would be
difficult to achieve that level of expertise since the task
is so meaningless and, apart from symmetry, there are no

principles by which general rules might be abstracted and applied. However, one could become reasonably competent at the task by acquiring some specific and some general declarative and procedural knowledge, as well as some heuristics relating to solution of Challenger. Specifically one might aim to acquire

1. declarative knowledge about a small number of patterns and their nearness to the goal;

2. declarative knowledge of the moves and the color changes they produce;

3. declarative knowledge about rotated/translated patterns;

4. a number of macroproductions incorporating productions that start from patterns at least four moves from the goal;

5. general heuristics such as

   (a) ability to anticipate the effects of a variety of moves on unfamiliar patterns and to recognize outcomes as familiar or unfamiliar patterns,

   (b) ability to set subgoals and select the most efficient procedures to attain those subgoals,

   (c) ability to recognize unfamiliar patterns as rotations/translations of familiar patterns and to transfer appropriate moves to rotated/translated patterns,

   (d) ability to add a new step to an old macroproduction and to increase the number and size of automatized paths stored in production memory.

3.4.1.2. Goal and focus of instruction

Any instructional program for Challenger would have to attempt

to provide a learner with some of the aforementioned components of expertise in the task. The goal of instruction should be to provide the learner with knowledge (declarative and procedural) that enables him/her to reach the goal state of Challenger from as many initial patterns (known and unknown) as possible.

The pilot study results indicated that there was the maximum number of paths that should be included in a single learning session. Therefore, for the purposes of this experiment, instruction focused on a subset of the solution paths from three initial patterns, each requiring a minimum of six moves to be transformed to the goal state. The solution paths on which subjects were specifically trained are shown in Figure 3.6 below. Paths 1 and 2 were selected because their initial patterns are instances of one general pattern. The paths leading to the goal from these patterns facilitate abstraction of more general rules for solving Challenger. In the case of some intermediate patterns in these three solution paths, it is possible to make more than one move to get closer to the goal. However, for the purposes of instruction, the learner was restricted to one particular move from each pattern in a path.

3.4.1.3. Two different instructional methods   The two instructional methods designed for use in this study were similar in the following respects:

1.   Initial declarative information provided about the goal structure of the task, the operations, i.e., moves, permitted to attain the subgoals/goal of the task, and the entire sequence of moves to solve Path 1.

2.   Initial opportunity (practice) to acquire procedural

Path 1

```
W G W      W G W      W W W      W W W      W W G      G W G      G G G
G W G -> G * W -> W W G -> G G * -> * G W -> W * W -> G W G
G G *      G W W      * G W      W W W      W W G      G W G      G G G
```

Path 2

```
* G W      W W W      W G W      W * W      G W G      G W G      G G G
G W G -> W * G -> G W W -> W G W -> W G W -> W * W -> G W G
G G W      G G W      * W W      W G W      W * W      G W G      G G G
```

Path 3

```
W W G      G W G      G W *      G * W      W W G      G W G      G G G
* G G -> W G G -> G W G -> G G W -> * G W -> W * W -> G W G
W G G      * G G      W W G      W W G      W W G      G W G      G G G
```

G = green cell.
W = white cell.
* = cursor position for correct move.

Figure 3.6. Solution paths on which instruction was given

knowledge of the moves and their effects on the "state" of
the task.

3.   A progressive part method of instruction (Phye, 1986,
      citing McGeogh & Irion, 1952) whereby
      (a)   subpart A of a procedure is presented and
            practiced until mastery occurs,
      (b)   subpart B is presented and practiced to mastery,
      (c)   subparts A and B are combined and practiced to

criterion,

(d) subpart C is introduced and practiced to
criterion,

(e) subparts A, B, and C are combined.

This process continues until the entire sequence of subtasks is mastered. This technique is similar to what Landa (1974) calls "the SNOWBALL PRINCIPLE OF DEVELOPING MULTIOPERATION PROCEDURES" (p. 198).

4. Instruction works backwards from the goal state of Challenger.

5. The learner is restricted to one move in cases where there is an alternative move which would also lead closer to the goal.

6. All learners are told to complete the instruction as quickly as possible.

7. No explicit reference is made to the symmetrical nature of the task.

The instructional methods designed for this study differed in the following respects:

1. The high-load instructional method is based on a theory of learning that advocates presentation of the correct steps in a procedure and imitative practice to criterion, with reinforcement for success but no cognitive processing support for the integration of the new knowledge with old. The low-load instructional method is based on a theory of learning that advocates the presentation of the incomplete information regarding the correct steps, together with an activity which forces the learner to actively construct and integrate the new procedure into existing knowledge structures.

2. The high-load method encourages the learner to focus on

the sequence of patterns in the path and the correct
moves that lead to patterns nearer the goal. A move
becomes associated with each pattern encountered. All
the learner has to do to progress to the end of the
path is to memorize the move to be made when each
pattern appears on the screen. The low-load method
encourages the learner to project the alternative
effects of different moves on a pattern in order to
reach a pattern closer to the goal. The learner is
forced to modify his/her erroneous projections and
learns some heuristics for approaching all Challenger
problems as well as three specific solutions.

3. The high-load method tells the learner exactly what
move to make to get to the next pattern in the path.
The low-load method allows the learner to try various
moves in order to find the move which leads to the next
pattern in the path.

The instructional programs will now be described in
detail. Each instructional program was replicated for each
of the three solution paths selected as the focus of
instruction. Therefore, one path (Path 1) is used here to
illustrate the description of the programs.

3.4.1.3.1. Elements of instruction common to both

programs   The introduction to both programs is similar.
First the task is described. Then goal state is shown. The
three possible distinct operations to change the color
configuration of the matrix are described. The learner is
asked to perform a move with the cursor on each cell and
observe the effect of the move on the color of the cells
in the matrix. The initial state of Path 1 appears on one
side of the screen and the goal state appears on the other.

The move required for each step towards the goal is described and executed as the next pattern on the solution path appears on the screen. Eventually, the entire path is visible and the appropriate cursor position for each move is indicated.

3.4.1.3.2. Elements of instruction only in high-load program

First, the state closest to the goal and the goal state are displayed, as in Figure 3.7.

```
                                 goal
                  G W G        G G G
                  W G W        G W G
                  G W G        G G G
```

G = green cell.

W = white cell.

Figure 3.7. High-load method: Display of initial pattern and goal state

Second, the learner is told to place the cursor on the appropriate cell of the initial state and press <RETURN> to change the pattern to that of the goal state. The screen is cleared, the initial state is presented, and the learner is asked to reproduce the correct move to get to the goal state. If the learner places the cursor on an incorrect cell, the consequences of that action are NOT shown; rather, the learner is told that it is the wrong operation and is asked to position the cursor again to execute the correct move.

Third, the state two moves back from the goal and the state one move back are displayed together, as in Figure 3.8, and the same process of demonstrating and allowing the

learner to practice the correct move to get from one to the other occurs.

```
                              subgoal
                    W W G      G W G
                    G G W      W G W
                    W W G      G W G
```

G = green cell.

W = white cell.

Figure 3.8. High-load method: Display of pattern and
            subgoal

Fourth, the goal state is added to the sequence and the learner is asked to produce the two consecutive moves that get from the initial pattern to the goal state. If the learner makes a mistake, the consequences of the incorrect move are not displayed. The cell on which the cursor should be placed is indicated so that the learner can make the correct move.

The whole set of steps is thus built up until the learner can reproduce, without error, the entire sequence of six operations to get from the initial state to the goal state. One complete run through the entire sequence of moves completes the instruction on each path.

3.4.1.3.3. Elements of instruction only in low-load program

First, the state closest to the goal and the goal state are displayed. Second, the learner is told to try to find the appropriate cursor position to get from the initial state to the goal state. The learner can try as many moves as he/she likes and, each time, the resulting pattern change is displayed. If the resulting pattern is not

the desired goal state, then the initial state is redisplayed and the learner can try another move. Once the learner has found the correct move, the initial state is presented again, and the learner is asked to reproduce the correct move to get to the goal state. If the learner places the cursor on an incorrect cell the consequences of that action are shown and the initial state is redisplayed so that the learner can try again.

Third, the pattern two moves back from the goal and the pattern one move back are displayed, and the same process of allowing the learner to find the move that gets from one pattern to the next occurs. Fourth, the goal state is added to the sequence and the learner is asked to produce and practice to criterion (once correctly) the two consecutive moves that get from the first state to the goal state. The learner is allowed as many practice trials as are necessary to reproduce the combination of moves correctly. The consequences of incorrect moves are shown before the initial state is redisplayed. The whole set of steps is thus built up until the learner can reproduce, the entire sequence of six operations to get from the initial pattern to the goal state. One complete run through the entire sequence of moves completes the instruction on each path. At all times during the low-load instructional program, the color changes resulting from the three types of moves possible are displayed on the right hand side of the screen.

The instructional and testing programs were programmed in Digital Authoring Language and delivered on Digital VT241 graphics terminals linked to a MicroVAX computer.

3.4.2. Fluid aptitude

A persistent pattern of correlations has been found among various aptitude tests (Snow, 1980). Three main clusters corresponding to

1. Gc - crystallized aptitude, using measures such as prior educational achievement, verbal knowledge, e.g., W-vocab, and reading comprehension;

2. Gf - fluid aptitude, using measures such as abstract reasoning tests, and some spatial and figural tests, e.g., Raven's Progressive Matrices or paper folding;

3. Gv - visualization aptitude, using figural and spatial relations tests such as WISC Block Design.

The distinction between Gc and Gf is often difficult to make because all instructional tasks and most complex ability tests involve a mixture of application from stored experience and adaptation to new problems (Snow & Lohman, 1984). The distinction between Gf and Gv is even more difficult to make because spatial tasks are often relatively novel and because the relevant performance assemblies also require adaptation (Snow, 1980).

Some studies have measured more than one ability factor, particularly Gc and Gf, and have found an ATI for one but not the other factor (e.g., Sharps, 1973). According to Snow and Lohman (1984),

> ATI research on instruction has not been successful thus far in providing convincing demonstration of the worth of the Gf/Gc/Gv distinction for the purposes of treatment design . . . . For purposes of analysis, at least, ATI research and much of the research on aptitude and learning is best served by defining a G or Gf first principal component and then distinguishing

the Gc - Gv contrast (p. 360).

Following Snow and Lohman's (1984) argument, scores on
the paper folding test from the Educational Testing Services
set of Cognitive Reference Tests were used as the measure of
fluid aptitude in this study. Scores on the paper folding
test were used for the purposes of investigating aptitude
treatment interaction. Reliabilities for the paper folding
test vary from .76 to .93 (French, Ekstrom, & Leighton,
1963). Work by Snow (1980) and others establishes the
validity of the test as a measure of Gf.

Raven's Standard Progressive Matrices (SPM) was used as
the measure of general ability on which subjects were
initially matched before random assignment to groups. If
that test had been timed, it could have also served as a
measure of Gf for analysis. According to Raven, Court and
Raven (1983), the internal consistency of the SPM test based
on split-half reliabilities is at least .90, with a modal
value of .91. Test-retest reliabilities range from .80 (at
longer intervals) to .90 (at shorter intervals). While "the
concurrent and predictive validities of the test vary with
age, possibly sex and homogeneity of the sample, the method
of assessment of the criterion to which the test will be
related, and the reliabilities of test and criterion
measures in the context considered" (Raven et al., 1983,
p. 8), the evidence suggests that Raven's SPM test is "one
of the purest and best measures of 'g' or general
intellectual functioning available" (p. 11). The
correlation between the two aptitude measures used in this
study was .59.

3.5. Dependent Variables: Measuring Instruments

3.5.1. Acquisition

The following measures of acquisition processes were employed:

1. The computer recorded the time and number of moves made by each subject for each path learned during instruction.
2. Performance on the recall and transfer tests allowed inference to cognitive processing during instruction.

3.5.2. Outcome measures

Four outcome measures were employed: immediate recall, delayed recall, near transfer, and far transfer. The transfer tests were classified according to Royer's (1986) two-dimensional scheme described in Chapter 2. Both transfer tests (labelled "near" and "far") were "literal" according to Royer's scheme, since neither required transfer beyond the domain of Challenger.

Each test consisted of 3 items, i.e., paths. A time limit of seven minutes was imposed on each item in each test. A "restart" option was provided whereby the initial pattern of the path would be redisplayed and one could try another set of moves to reach the goal. A maximum of nine restarts was allowed for each item. After 15 consecutive moves without success, an automatic restart of the item occurred. For each subject, number of moves made in each item, sequence of moves made in each item, and number of successful solutions in each test were recorded by the computer.

3.5.2.1. Immediate recall test   Immediately after instruction, subjects were asked to reproduce the three procedures that they had learned.

3.5.2.2. Delayed recall test   One month after instruction, subjects were asked to reproduce the entire procedures that they had learned.

3.5.2.3. Near transfer test   The near transfer test consisted of three items. The first item required solution from an initial pattern which was an intermediate state in one of the three paths on which instruction was provided. The second item required solution from an initial pattern which was a rotation of an intermediate pattern in one of the paths on which instruction was provided. The third item required solution from an initial pattern that was a rotation of one of the initial patterns on which instruction was provided. Figure 3.9 below shows the patterns that were the initial states of the near transfer items. These three items were deemed to require literal near transfer of the procedural knowledge acquired in the instructional programs because either the initial patterns of the items or rotations of them were encountered during instruction. Thus they were testing mastery of the basic skills (Royer, 1986) required for expertise in the Challenger task.

3.5.2.4. Far transfer test   The literal far transfer test consisted of three items. The first item required solution from an unfamiliar initial pattern which required one move to get to a familiar pattern, i.e., one which was an initial pattern of a trained path. The second item required solution from an unfamiliar initial pattern

```
W W W
W W G        PATH 1, PATTERN C, 4 MOVES FROM GOAL
G G W


W W G
G G W        Rotation of PATTERN D, PATH 3, 3 MOVES FROM GOAL
G G W


G W W
G G G        Rotation of PATTERN 1, PATH 3, 6 MOVES FROM GOAL
G G W
```

G = green cell.
W = white cell.

Figure 3.9. Near transfer items

requiring two moves to get to a familiar pattern, i.e., one
encountered during instruction. The third item required
solution from an initial pattern six moves removed from the
goal state, but NOT a rotation/translation of the patterns
encountered during instruction. Figure 3.10 below shows the
patterns that were the initial states of the far transfer
items. These three items were deemed to require literal far
transfer of the procedural knowledge acquired in the
instructional programs because the initial patterns of the
items were all unfamiliar and required generalization of the
basic skills (Royer, 1986) required for expertise in the
Challenger task.

```
G W G
G G W  1 MOVE BACK FROM PATTERN A, PATH 2, 7 MOVES FROM GOAL
G G W



W G W
G G W  2 MOVES BACK FROM PATTERN A, PATH 2, 8 MOVES FROM GOAL
G G W



W W W
G G W  UNFAMILIAR PATTERN, 6 MOVES FROM GOAL
G W W
```

       G = green cell.
       W = white cell.

Figure 3.10. Far transfer items

3.6. Research Procedure

1.   Subjects were randomly assigned to treatment groups
     following matching on general ability scores (Raven's
     SPM).
2.   Subjects completed computer-based instruction
     individually in February 1988.
3.   Subjects took immediate recall and transfer tests
     immediately after completion of instruction.
4.   Subjects took delayed recall test in March 1988,
     approximately one month after instruction.
7.   Paper folding test was administered in March 1988.

3.7. Methods of Analysis

3.7.1. Type of data

For each subject in the sample, the following data were obtained:

1. Aptitude Data

    Scores on a paper-folding test were used as a measure of fluid aptitude.

2. Acquisition Data

    For each path, time on instruction and number of moves made were used as measures of acquisition speed.

3. Outcome Test Data

    For each item in each test, solution or non-solution, number of moves made, and sequence of moves made during solution of the item were recorded by the computer and used to form continuous measures of immediate recall, delayed recall, near transfer and far transfer of the procedures learned during instruction.

3.7.2. Statistical analysis procedures

The mean score on each independent and dependent measure for each treatment group, were obtained. In the case of fluid aptitude and acquisition data, the differences between the treatment group means were compared using t-tests.

In order to examine correlations and regression models, particularly to determine if fluid aptitude interacted with instructional method, continuous dependent measures were formed for immediate and delayed recall, and for near and far transfer. The criteria by which the dependent measures

were formed were number of correct solutions, number of
partial solutions and number of moves made to reach
solution; for those who succeeded in solving an item, the
less the number of moves, the greater the ability to solve
the item. The following is a full description of how the
continuous outcome measures were formed.

1. For those who had solved an item within the 7 minute
   time limit:
   a top score of 20 was assigned to subjects who solved
   the item in the minimum number of moves plus one;
   a score of 15 was assigned to subjects who solved the
   item in two more than the minimum but not more than 20
   moves more than the minimum;
   a score of 10 was assigned to subjects who solved the
   item in more than the minimum plus 20 moves.
   Thus, the score for anyone who solved an item ranged
   from 10 to 20 for that item.

2. For those who had not reached a solution to an item
   within the time limit, points were assigned for partial
   solutions according to the following scheme:
   0 points if first move toward solution was never
   attempted when initial pattern was displayed;
   1 point if first move toward solution was made when
   initial pattern was displayed;
   2 points if first two moves toward solution were made
   in sequence from initial pattern;
   3 points if first 3 moves toward solution were made in
   sequence from initial pattern;
   4 points if first 4 moves toward solution were made in
   sequence from initial pattern;
   5 points if first 5 moves (or more in the case where
   the minimum number of moves to reach goal was greater

than 6) toward solution were made in sequence from
initial pattern;

.2 extra point was added for each time the correct
partial set of moves was made, but no score for partial
solution of an item could exceed 5 points.

Thus, the score for any subject who did not completely
reach the goal on an item could range from 0 to 5.

The complete range of scores on any item was from 0 to
20. Since each test consisted of 3 items, the range of
scores on any test was from 0 to 60.

A stepwise linear regression was run on the following
non-additive model for each continuous dependent measure:

$$Yi = B0 + B1(X1) + B2(X2) + B3(X1*X2) + Ei$$

where

Yi = dependent variable;

B0 = intercept;

B1 = coefficient for treatment variable;

B2 = slope for fluid aptitude;

B3 = coefficient for interaction effect of the two
independent variables;

Ei = error term.

The significance of main and interaction effects were
tested. Regression lines were plotted where appropriate.

3.8. Empirical Hypotheses

The empirical hypotheses to be tested were as follows:

1. There are significant differences between the
   acquisition data of the two treatment groups, i.e.,
   high-load instruction takes significantly less time and
   significantly less moves than does low-load treatment.

2. High-load instruction on procedures results in better

immediate recall of procedures than does low-load
instruction.

3. Low-load instruction on procedures results in
    significantly better delayed recall than does high-load
    instruction.

4. Low-load instruction on procedures results in
    significantly better near and far transfer of
    procedures than does high-load instruction.

5. For transfer outcomes, level of fluid aptitude (Gf)
    interacts significantly with instructional method.
    High Gf subjects have higher levels of transfer with
    high-load instruction; low Gf subjects have higher
    levels of transfer with low-load instruction. In other
    words, low-load instruction compensates for lack of the
    aptitude that is positively correlated with ability to
    transfer, but interferes with high aptitude for
    transfer. The regression lines will look like those in
    Figure 3.11.
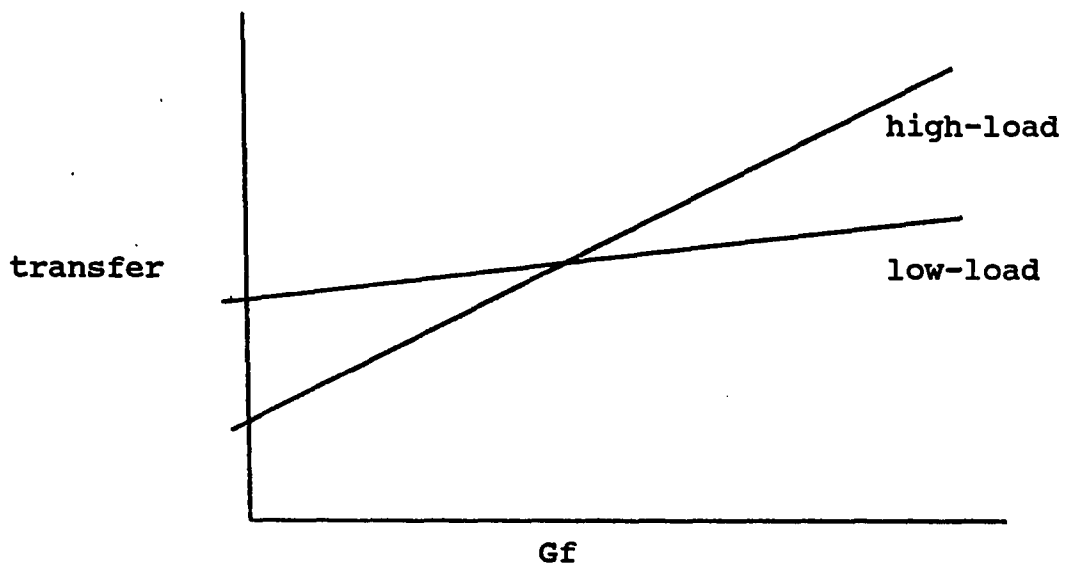
Figure 3.11. Hypothesized regression lines for transfer

4. RESULTS

4.1. Introduction

This chapter presents the results of the statistical analysis of data gathered in the study. The General Linear Model was used to test all hypotheses relating to outcome measures (recall and transfer), following the procedure outlined by Pedhazer (1982, pp. 436-471).

Before presenting the results of the multiple regression analysis in this chapter, results relating to data gathered during instruction (acquisition data), and descriptive statistics for the independent and dependent variables are reported. For all tests of significance, alpha was set at .05. The independent samples t-test was used where the t-test was appropriate. For all t-tests, homogeneity of variance was tested and the resulting F value and probability levels are reported together with the appropriate t estimate (pooled or separate variance). Since the research was exploratory, two-tailed tests of significance were employed for testing all hypotheses.

4.2. Acquisition Data

The statistical hypotheses relating to the acquisition data of the two treatment groups were:

Hypothesis 1(a): There is no significant difference between time to complete high-load and low-load instruction.

Hypothesis 1(b): There is no significant difference between the number of moves made in high-load and low-load instruction.

T-tests were used to test these two hypotheses. Table 4.1
presents relevant means, standard deviations, t values and
probability levels. The average time for students in the
high-load group was 47.80 minutes compared with an average
of 56.91 minutes in the low-load group; this difference was
significant at the .0005 level. Therefore, null hypothesis
1(a) was rejected and it was concluded that high-load
instruction on procedures takes less time than does low-load
instruction. There were no significant differences between
number of moves made in high-load (mean = 89.88) and low-
load (mean = 92.33) instruction, i.e., in practicing each
move and combination of moves in each path. Therefore, null
hypothesis 1(b) was not rejected.

Table 4.1. Acquisition: Time spent (in minutes) and number
of moves made during instruction, by group

Group[a]	n	Time					Moves				
		Mean	SD	t-val.	df	t-prb.	Mean	SD	t-val.	df	t-prb.
HL	40	47.80	9.54				89.88	13.83			
				4.09	78	<.0005			.63	78	.532
LL	40	56.91	10.38				92.33	20.45			

[a]HL = subjects in high-load treatment group; LL =
subjects in low-load treatment group.

4.3. Descriptive Data

4.3.1. Independent variable: Fluid aptitude

The Paper Folding test from the ETS Kit of Cognitive Reference Tests (French, Ekstrom, & Leighton, 1963) was used as the instrument to measure the fluid aptitude (Gf) of subjects in this study. Out of a possible total of 20, scores for the sample ranged from 5 to 20 with a mean of 13.88 and a standard deviation of 3.31. The alpha reliability coefficient for the scores of the sample in this study was .80. The distribution of scores was approximately normal. There was no significant difference between the means (t = .13; df = 78; p = .894) or variances (F = 1.65; df = 1, 78; p = .121) of Gf scores for the two treatment groups (Table 4.2).

Table 4.2. Fluid aptitude: Descriptive statistics by group

Group[a]	n	Mean	SD	F-value	F-prob.	t-value	df	t-prob.
LL	40	13.93	2.90					
				1.65	.121	.13	78	.894
HL	40	13.83	3.72					

[a]HL = subjects in high-load treatment group; LL = subjects in low-load treatment group.

4.3.2. Dependent variables

For each of the four dependent variables, immediate recall, delayed recall, near transfer, and far transfer, a continuous variable representing a combination of number of correct solutions, and number of moves made to achieve solution, was formed; a complete description of how these continuous dependent variables were formed was given in Chapter 3. Scores on each variable ranged from 0 to 60. Table 4.3 presents the mean and standard deviation on each variable for each treatment group and for the total sample.

Table 4.3. Dependent variables: Descriptive statistics

	Mean			SD		
	Group[a]		Total	Group		Total
Variable	LL (n=40)	HL (n=40)	Sample (n=80)	LL (n=40)	HL (n=40)	Sample (n=80)
Imm. Recall	34.00	28.67	31.34	20.72	22.09	21.45
Del. Recall	22.35	21.63	21.99	19.66	18.97	19.20
Near Trsfr.	35.79	34.32	35.06	13.21	17.33	15.33
Far Trsfr.	14.55	8.80	11.67	15.18	9.09	12.76

[a]HL = subjects in high-load treatment group; LL = subjects in low-load treatment group.

4.4 Regression Analysis

Four regression models with first order interaction terms were tested using the stepwise procedure. The generic

model was

$$Yi = Bo + B1(X1) + B2(X2) + B3(X1*X2) + Ei$$

where X1 was the continuous variable, fluid aptitude, and X2 was the treatment variable, instructional method. The criterion variable (Yi) was either immediate recall (I), delayed recall (D), near transfer (N), or far transfer (F).

Initially, for each model, residuals were examined for violations of assumptions of regression (normality, linearity, homogeneity of variance), and for outliers. In addition, the correlations among the independent variables were inspected for evidence of collinearity. None of the four models produced residuals which departed visibly from the assumption of normality; therefore, raw data were used for the dependent variables. From the correlations between treatment group and aptitude variables, no evidence of collinearity was found (the correlation between group and Gf was .0152). No outliers, i.e., data points with standardized residuals greater than 3 or less than -3, were detected.

Table 4.4 below presents the proportion of variance accounted for (i.e, R-squared) by each successive predictor entered, and the overall F value and significance level for each of the models. The model was most appropriate for the variance in near transfer; the full model accounted for 26% of the variance. The partial F-tests for the significance of the relationships between particular independent variables and each of the four dependent variables are presented in Table 4.5 below.

The specific results for the significance of the interaction and main effects on each criterion variable will now be described. Since there was only one degree of freedom in the partial F-tests, they are equivalent to

Table 4.4. Summary of results for stepwise regressions

Criterion[b] Variable	Predictors Entered[a]			Overall F-value	df	p
	T	A	T*A			
I	.0156	.0895	.0959	2.68775	3,76	.0523
D	.0004	.0982	.1046	2.95989	3,76	.0375
N	.0023	.2238	.2637	9.07290	3,76	.0000
F	.0513	.0796	.0798	2.19690	3,76	.0953

[a]T = treatment; A = fluid aptitude; T*A = interaction.

[b]I = immediate recall; D = delayed recall; N = near transfer; F = far transfer.

testing the significance of individual beta coefficients in the appropriate (full or reduced) model.

4.4.1. Immediate recall

The statistical hypotheses relating to immediate recall were:

Hypothesis 2(a): There is no significant interaction effect of instructional method and fluid aptitude on immediate recall.

Hypothesis 2(b): There are no significant main effects of fluid aptitude or treatment on immediate recall.

In order to test hypothesis 2(a), the full regression model, $I = Bo + B1(A) + B2(T) + B3(A*T) + Ei$, was run and the beta coefficient for the interaction term was tested for significance. The result of that test revealed that there

Table 4.5. Partial F-tests on single independent variables

Relationship of Interest [a]	F	df	p
I.T*A/T,A	-.734	1,76	.4652
I.A/T	2.499	1,77	.0146**
I.T/A	1.112	1,77	.2696
I.A	6.315	1,78	.0140**
I.T	1.239	1,78	.2910
D.T*A/T,A	-.736	1,76	.4642
D.A/T	2.891	1,77	.0050**
D.T/A	.130	1,77	.8966
D.A	8.478	1,78	.0047**
D.T	.0278	1,78	.8681
N.T*A/T,A	-2.030	1,76	.0459**
N.A/T,T*A	5.020	1,76	.0000**
N.T/A,T*A	2.072	1,76	.0417**
N.A	22.269	1,78	.0000**
N.T	.18202	1,78	.6708
F.T*A/T,A	.129	1,76	.8974
F.A/T	1.538	1,77	.1280
F.T/A	2.048	1,77	.0440**
F.A	2.367	1,78	.1280
F.T	4.218	1,78	.0433

[a] T = treatment; A = fluid aptitude; T*A = interaction; I = immediate recall; D = delayed recall; N = near transfer; F = far transfer; / = "after".

**Significant at or beyond .05 level.

was no significant interaction effect between the two independent variables on immediate recall (b3 = -1.069571, t = -.734, p = .4652, df=76). Therefore, null hypothesis 2(a) was not rejected; the relationship between fluid ability and immediate recall was similar in both treatment groups.

In order to test for the significance of main effects,

i.e., hypothesis 2(b), the reduced regression model,
$I = Bo + B1(A) + B2(T) + Ei$, was run. To determine if the
common regression coefficient was significant, the beta
coefficient for the aptitude variable was tested first. The
result of that test indicated that there was a significant
relationship between fluid aptitude and immediate recall ($b1$
= 1.759956, t = 2.499, p = .0146, df = 77). To determine if
the intercepts were significantly different, the beta
coefficient for the treatment variable was tested. The
result of that test indicated that there was not a
significant relationship between treatment, i.e,
instructional method, and immediate recall ($b2$ = 5.154004,
t = 1.112, p = .2696, df = 77).

In order to determine the precise extent of the
relationship between fluid aptitude and immediate recall,
the regression model containing only the aptitude variable,
i.e., $I = Bo + B1(A) + Ei$, was run and its beta coefficient
(i.e., slope) was tested for significance. The result of
that test indicated that the relationship between fluid
ability and immediate recall was significant at the .05
level ($b1$ = 1.771849, t = 2.513, p = .0140, df = 78). The
actual correlation between fluid aptitude and immediate
recall was .2737; this is also the correlation between the
immediate recall scores predicted by the regression model
and the observed immediate recall scores. The proportion of
variance in immediate recall that could be accounted for by
Gf was 7.49% (i.e., r-squared). Null hypothesis 2(b) was
rejected in the case of fluid aptitude but not in the case
of treatment; the higher the level of fluid aptitude, the
higher the level of immediate recall, regardless of
instructional method. Figure 4.1 shows a plot of the common
regression equation, $E(I) = 6.75 + 1.7718(A)$.

Figure 4.1. Regression of immediate recall on Gf

4.4.2. Delayed recall

The statistical hypotheses relating to delayed recall were:

Hypothesis 3(a): There is no significant interaction effect of instructional method and fluid aptitude on delayed recall.

Hypothesis 3(b): There are no significant main effects of fluid aptitude or treatment on delayed recall.

In order to test hypothesis 3(a), the full regression model, $D = Bo + B1(A) + B2(T) + B3(A*T) + Ei$, was run and the beta coefficient for the interaction term was tested for

significance. The result of that test revealed that there
was no significant interaction effect between the two
independent variables on delayed recall (b3 = -.955159,
t = -.736, p = .4642, df = 76). Therefore, null hypothesis
3(a) was not rejected; the relationship between fluid
aptitude and delayed recall was similar in both treatment
groups.

In order to test for the significance of the main
effects, i.e, hypothesis 3(b), the reduced regression model,
D = Bo + B1(A) + B2(T) + Ei, was run. To determine if the
common regression coefficient was significant, the beta
coefficient for the aptitude variable was tested for
significance first. The result of that test indicated that
there was a significant relationship between fluid aptitude
and delayed recall (b1 = 1.813698, t = 2.891, p = .0050, df
= 77). To determine if the intercepts differed
significantly, the beta coefficient for the treatment
variable was tested. The result of that test indicated that
there was not a significant relationship between treatment,
i.e, instructional method, and delayed recall (b2 = .538630,
t = .130, p = .8966, df = 77).

In order to determine the precise extent of the
relationship between fluid aptitude and delayed recall in
this study, the regression model containing only the
aptitude variable was run and its beta coefficient (i.e.,
slope) was tested for significance. The result of that test
indicated that the relationship between fluid ability and
delayed recall was significant at the .05 level (b1 =
1.814941, t = 2.912, p = .0047, df = 78). The actual
correlation between fluid aptitude and delayed recall was
.3131. The proportion of variance in delayed recall that
could be accounted for by Gf was 9.8%. Null hypothesis 3(b)

was rejected in the case of fluid aptitude but not in the case of treatment; the higher the level of fluid aptitude, the higher the level of delayed recall, regardless of instructional method. Figure 4.2 shows a plot of the common regression equation, $E(D) = -3.19 + 1.8149(A)$.
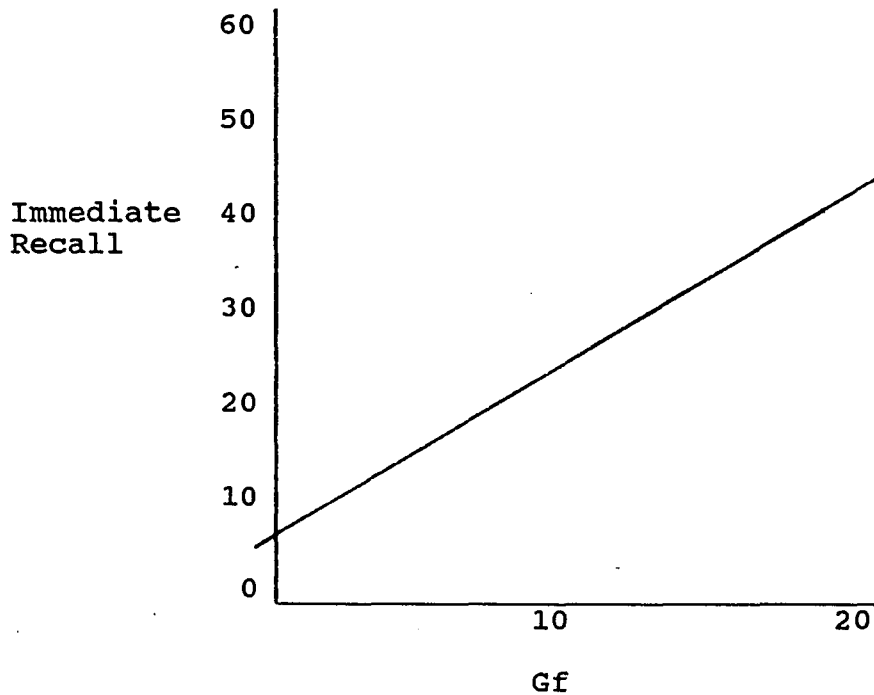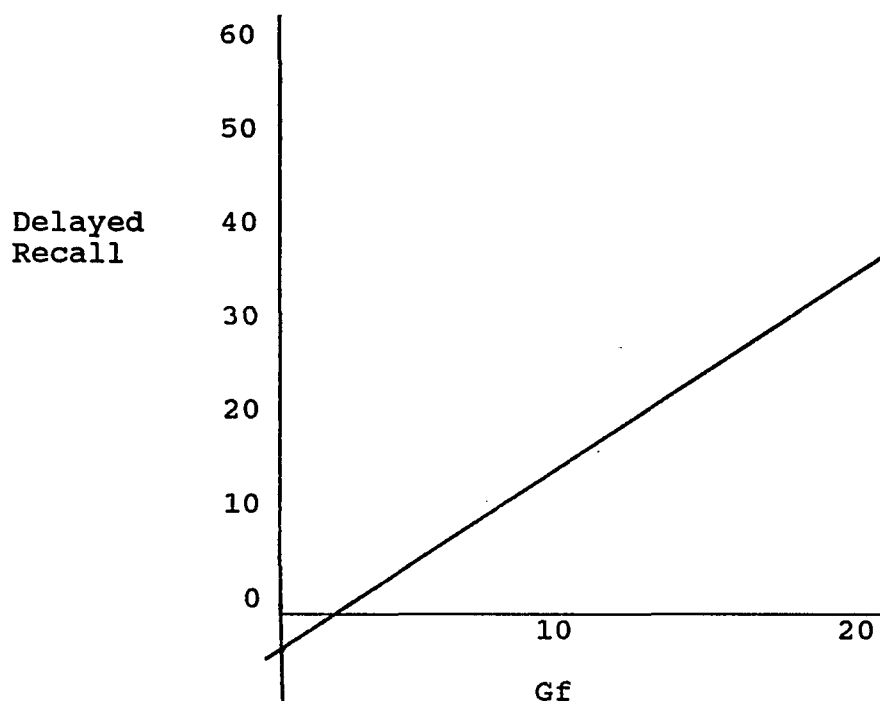
Figure 4.2. Regression of delayed recall on Gf

4.4.3. Near transfer

The statistical hypotheses relating to near transfer were:

Hypothesis 4(a): There is no significant interaction effect of instructional method and fluid aptitude on near transfer.

Hypothesis 4(b): There are no significant main effects of
fluid aptitude or treatment on near
transfer.

In order to test hypothesis 4(a), the full regression
model, $N = Bo + B1(A) + B2(T) + B3(A*T) + Ei$, was run and
the beta coefficient for the interaction term was tested for
significance. The result of that test revealed that there
was a significant interaction effect between the two
independent variables on near transfer ($b3 = -1.907998$,
$t = -2.030$, $p = .0459$, $df = 76$). Therefore, null hypothesis
4(a) was rejected; the relationship between fluid aptitude
and near transfer was significantly different in the two
treatment groups.

In order to determine the precise relationship between
fluid aptitude and near transfer for each group, two
regression equations were formed as follows:
The overall regression equation for the model was
$N = -5.739012 + 27.74911(T) + 2.897578(A) - 1.907998(A*T)$
The intercept in this equation is the intercept for the
high-load group and the beta coefficient for the aptitude
variable is the slope of the equation for the high-load
group. The beta coefficient for treatment in this equation
is the deviation of the intercept for the low-load group
from the intercept for the high-load group; therefore, the
intercept for the low-load group is
$-5.739012 + 27.74911 = 22.01009$.
The slope of the equation for the low-load group is
calculated by adding the coefficient associated with the
interaction term in the overall equation to the beta
coefficient of the aptitude variable; therefore the slope
for the low-load group is $2.897578 - 1.907998 = .98958$.
The separate equations are:

High-load: E(N) = -5.739012 + 2.897578(A)
Low-load: E(N) = 22.01009 + .98958(A)
The point of intersection of the two regression lines is
(22.01009 + 5.73901)/(2.897578 - .98958) = 14.54357.

Figure 4.3 shows a plot of the two regression lines.
Since the point of intersection was within the range of
scores on the aptitude variable, the interaction was
disordinal. This means that the low-load treatment was
superior for students with lower levels of fluid aptitude up
to 14.5, while the high-load treatment was superior for
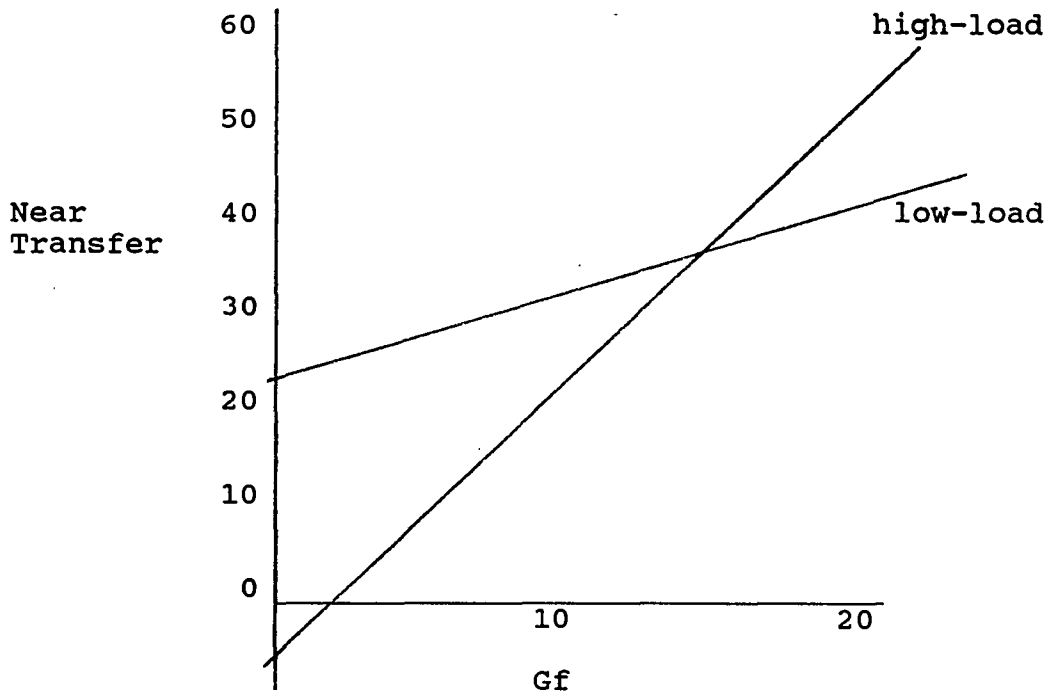students with higher levels of fluid aptitude (from 14.5 and
up).

Figure 4.3. Regression of near transfer on Gf for each
             treatment group

In order to test for the significance of the main effects, i.e., hypothesis 4(b), the beta coefficients for those variables in the full model (i.e., with interaction term) were tested for significance. The effect of both variables was significant; for fluid aptitude: $b1 = 2.897578$, $t = 5.020$, $p < .0005$, $df = 76$); for treatment: $b2 = 27.74911$, $t = 2.072$, $p = .0417$, $df = 76$). Therefore, null hypothesis 4(b) was rejected; both main effects were significant.

The actual correlation between fluid aptitude and near transfer was .2169 for the low-load group and .6219 for the high-load group. The proportion of variance in near transfer that could be accounted for by the two variables and their interaction was 26.37%.

4.4.4. Far transfer

The statistical hypotheses relating to far transfer were:

Hypothesis 5(a): There is no significant interaction effect of instructional method and fluid aptitude on far transfer.

Hypothesis 5(b): There are no significant main effects of fluid aptitude or treatment on far transfer.

In order to test hypothesis 5(a), the full regression model, $F = Bo + B1(A) + B2(T) + B3(A*T) + Ei$, was run and the beta coefficient for the interaction term was tested for significance. The result of that test revealed that there was no significant interaction effect between the two independent variables on far transfer ($b3 = .113207$, $t = .129$, $p = .8974$, $df = 76$). Therefore, null hypothesis 5(a)

was not rejected; the relationship between fluid aptitude and far transfer was similar in both treatment groups.

In order to test for the significance of the main effects, i.e., hypothesis 5(b), the reduced regression model, $F = Bo + B1(A) + B2(T) + Ei$, was run. To determine if the common regression coefficient was significant, the beta coefficient for the aptitude variable was tested for significance. The result of that test indicated that the relationship between fluid aptitude and far transfer was NOT significant (b1 = .648128, t = 1.538, p = .1280, df = 77). Therefore, to test for the significance of the effect the treatment variable, the beta coefficient for the treatment variable in the reduced regression model with only the treatment variable included, $F = Bo + B1(T) + Ei$, was tested for significance (this is equivalent to a t-test on the difference between the means of the two treatment groups). The result of that test indicated that there was a significant difference between the far transfer scores of the two treatment groups (b1 = 5.745, t = 2.054, p = .0433, df = 78). The treatment variable, instructional method, accounted for 5.13% of the variance in far transfer scores. Null hypothesis 5(b) was rejected in the case of treatment but not in the case of fluid aptitude; the low-load treatment produced higher levels of far transfer than did the high-load instructional method regardless of level of fluid aptitude of the students.

4.5. Summary

1. ACQUISITION: High-load instruction on procedures takes less time than does low-load instruction; both require similar numbers of moves.

2. IMMEDIATE RECALL: The higher the level of fluid aptitude, the higher the level of immediate recall, regardless of instructional method.

3. DELAYED RECALL: The higher the level of fluid aptitude, the higher the level of delayed recall, regardless of instructional method.

4. NEAR TRANSFER: The effects of both fluid aptitude and treatment were significant, and there was a significant disordinal interaction effect between them, in relation to the near transfer criterion variable. The low-load treatment was superior for students with lower levels of fluid aptitude up to 14.5, while the high-load treatment was superior for students with higher levels of fluid aptitude (from 14.5 and up).

5. FAR TRANSFER: The low-load treatment produced higher levels of far transfer than did the high-load treatment regardless of level of fluid aptitude of the students.

5. SUMMARY, DISCUSSION, AND RECOMMENDATIONS

5.1. Summary

The purpose of this study was to investigate the relative effectiveness of two instructional methods on the recall and transfer of procedures, and to determine if level of fluid aptitude would interact with the methods. The methods differed in the degree of support provided for active construction of personally meaningful procedural knowledge. The high cognitive load instructional method provided complete information about the steps in each procedure together with practice, but little opportunity for error or corrective feedback. The low cognitive load instructional method initially presented incomplete information about steps in a procedure and forced the learner to actively construct the steps by a process of trial, error and implicit feedback. Learners in both treatment groups were able to perform the sequence of steps in each procedure without error at the end of the instructional program.

Based on previous research on transfer of learning and ATI, it was hypothesized that each instructional method would be beneficial for particular performance outcomes and would also interact with level of fluid aptitude. Specifically, it was predicted that

1. the high-load method would be best for immediate recall, but the low-load method would be best for delayed recall and transfer;

2. learners with lower levels of fluid aptitude would profit most from the low-load treatment, in terms of ability to transfer the procedures learned, whereas

learners with higher levels of fluid aptitude would
achieve higher transfer with the high-load treatment.
It was also reasoned that the use of the computer as an
environment for the kind of interactivity that promotes
active cognitive processing, the selection of a novel and
complex task, and the measurement of a variety of
performance outcomes, would permit the identification of
specific elements of instruction that are "mathemagenic" for
learners with different levels of fluid aptitude.

There were two independent variables in the study:
instructional method (two levels: high-load and low-load),
and fluid aptitude (a continuous measure). There were four
dependent variables: immediate recall, delayed recall, near
transfer, and far transfer. The procedures to be learned
were three solution paths for a computer-based task,
Challenger. The important results of the study were

1. instructional method did not affect immediate or
    delayed recall of procedures. A learner's ability to
    immediately recall, or to recall one month later, the
    procedures learned was similarly related to fluid
    aptitude regardless of instructional method;

2. fluid aptitude was not related to far transfer of the
    procedures learned. The low-load instructional method
    led to greater far transfer than did the high-load
    method, regardless of fluid aptitude of the learner;

3. scores on the near transfer test were the highest of
    all the outcome measures for both groups. However, the
    relationship between fluid aptitude and near transfer
    was different in each treatment group. In the high-
    load treatment, there was a steep regression line,
    indicating that the higher the level of fluid aptitude,
    the greater the near transfer score. In the low-load

treatment, the regression line was shallow, indicating that fluid aptitude was not significantly correlated with near transfer. The low-load treatment increased the near transfer scores of the learners with lower Gf and depressed the scores of the learners with higher Gf, relative to the scores of learners with similar fluid aptitude in the high-load treatment.

5.2. Discussion

There are a number of reasons why the results of this study may not generalize beyond the context of the study itself. Firstly, the size of the sample used was small (40 in each treatment group) and consisted of college student volunteers. Secondly, the treatments were arbitrarily fixed levels of a continuous variable, cognitive load of instruction. However, the findings did concur with much of current theory and previous research. In a few respects the findings differed from current theory and previous research. This discussion will consider the findings which were similar to those of previous research first, relating them to Anderson's (1983) theory of learning and Snow and Lohman's (1984) theory of aptitude for learning from instruction. The elements of the instructional methods that were critical to the outcomes obtained will be identified. Secondly, the findings which departed from current theory and previous research will be discussed and aspects of the study which might account for those departures identified.

5.2.1. Agreement with previous research and theory

The findings which bore out the conclusions of previous research and theory were:

1.   delayed recall of procedures was a function of fluid aptitude;

2.   there was a disordinal aptitude-treatment interaction effect on near transfer.

Cronbach and Snow (1977) concluded that delayed recall tests were better measures, than were immediate recall tests, of the moderating influence of aptitude on learning. Immediate recall tests would mask differences in the extent to which knowledge had been actively processed and integrated with existing knowledge in memory. Subsequent interaction with the environment would interfere most with task-specific procedures which had been compiled in isolation, without the extraction of more general rules. Fluid aptitude is related to the kind of processing that Anderson (1983) characterizes as the interpretive stage of knowledge acquisition, the stage where new information is interpreted through existing procedures and rendered less susceptible to interference once stored in production memory. Thus, it would be expected that the ability to retrieve task-specific procedures after a long period of time would be highly correlated with fluid aptitude. The delayed recall of a procedure would include reconstruction of missing elements of the procedure by applying more general heuristics to relevant declarative knowledge (principles and concepts acquired during instruction); only learners who had initially constructed the task-specific procedures for themselves would be able to reconstruct those procedures. This seems to have been the case in this study;

subjects with higher fluid aptitude actively processed the procedures before compiling them in production memory and were therefore better able to reconstruct the procedures when required to use them one month after instruction.

A better indicator, than delayed recall, of the effects of fluid aptitude on learning, is transfer of learned procedures to novel problems (Snow & Lohman, 1984). In this study, the scores on the near transfer test were higher than either immediate or delayed recall; that is probably due to the fact that the near transfer test was taken immediately after the immediate recall test which provided additional practice on the learned procedures, whereas the delayed recall test was taken one month after initial instruction. Fluid aptitude was significantly related to near transfer. However, that relationship was much more pronounced when the instructional method placed the burden of cognitive processing on the learners themselves, than when support for appropriate cognitive processing was embedded in the instruction.

Although the high-load treatment broke the task down into its component steps, demonstrated the correct behavior at each step, and allowed the learners to practice the correct steps until they could reproduce the six steps in sequence, it did not encourage the learners to abstract more general heuristics for solving Challenger problems. One such heuristic is the projection of the effects of a number of moves on the color configuration of the matrix before selecting the move most likely to bring one closer to the goal. Unless a learner him/herself spontaneously tried to integrate and compile more general procedures, he/she would end up storing no more than three separate procedures in memory, one for each particular solution path learned. As

long as he/she did not forget any parts of those procedures, and could recognize the configurations of Challenger to which they applied, then he/she would be able to perform those three solution paths, but no others.

Learners with low levels of fluid aptitude do not spontaneously "interpret" new information through existing task-independent procedures, because they do not possess the "metacognitive" procedures that characterize learners with high fluid aptitude (Snow & Lohman, 1984). Therefore, instruction that does not provide support for the interpretive stage of knowledge acquisition (Anderson, 1983), such as the high-load treatment in this study, will leave learners, who have lower fluid aptitude, with procedures which are tied to the stimuli for which they have been presented as the correct response. Learners with higher Gf are served well by high-load methods because they are given maximum freedom to apply their own personal strategies to make the procedures more meaningful and more generalizable.

Instruction that provides support for cognitive processing by forcing a particular strategy for the active construction of complete procedures is of benefit to learners with lower Gf; it compensates for their lack of metacognitive skills. However, for learners with higher Gf, such low-load instruction attempts to substitute unfamiliar and less automatic strategies for the existing successful strategies they possess. As learners with higher Gf attempt to adopt the imposed novel strategy, it competes with their existing metacognitive skills and the result is a weakening of their old strategies and an incomplete adoption of the novel strategy (Clark, 1989). That theory is supported by the findings of this study in relation to near transfer.

The low-load treatment forced all learners to interpret each new step towards solution of Challenger by violating their expectations about the next move. The learners saw the results of the erroneous moves they made and had a chance to "find" the correct move before compiling, i.e., composing and proceduralizing it (Anderson, 1983). The limited amount of instruction that was provided in this study focused on supporting the "interpretive" stage of learning and did not address the "tuning" stage which should take place after task-specific procedures have been compiled. However, the support that was provided led to a real improvement in the ability of learners, with lower levels of Gf, to transfer the procedures learned to problems where the initial states were related to, but were not the same as, familiar states (e.g., a rotated version of a familiar initial state).

It seems reasonable to conclude that the low-load instructional method was appropriate for learners who would not otherwise have been able to make that level of generalization for themselves. The high-load instructional method was more appropriate for learners who could make such generalizations without any support. It seems that the key element in the low-load treatment that was "mathemagenic" for learners with lower Gf was the opportunity to try out their own "hypotheses" or theories regarding the next step in the solution, the implicit feedback which allowed them to compare the outcome of their action with the desired outcome, and the modification of their hypotheses until they constructed the correct move for themselves. This is similar to the key element of some instructional simulations and microworlds (Papert, 1980; Hooper, 1986). The key element in the high-load treatment that was "mathemagenic"

for the learners with higher Gf was the absence of any
guidance on the cognitive strategy for acquiring more
generalizable procedures relating to the task; learners were
left to exercise whatever interpretive/metacognitive skills
they had. Learners who had high metacognitive skills, and
either automatically or consciously applied them to the
incoming information on the correct steps in the procedures,
would become the most expert solvers of near transfer
Challenger problems.

5.2.2. Departures from previous research and theory

The findings differed from previous research and theory
in the following respects:

1. there was no difference in the immediate recall of
    learners in the two treatment groups and immediate
    recall was a function of fluid aptitude;

2. the same relationship between delayed recall and fluid
    aptitude pertained for learners in both treatment
    groups;

3. far transfer was not a function of fluid aptitude; the
    low-load treatment led to greater levels of far
    transfer for learners of all aptitude levels.

Based on the distinctions between behavioral and
cognitive methods of instruction (Shuell, 1986; Royer,
1986), it would have been expected that a method of
instruction that encouraged memorization of a sequence of
steps to solve a particular problem would have led to better
immediate recall of the procedure than would a method that
encouraged the abstraction of more general procedures. That
is, the high-load method should have been more effective
than the low-load method in terms of number of correct

solutions, or at least more efficient in terms of speed or number of actions necessary. In view of Snow and Lohman's (1984) differentiation between fluid and crystallized aptitude, it would also have been expected that crystallized, not fluid, aptitude would be related to ability to immediately recall a procedure. Crystallized aptitude was not measured in this study, but the immediate recall scores were significantly related to fluid aptitude.

A possible reason for the lack of difference in the immediate recall scores of the two treatment groups is the fact that both treatments ensured that, by the end of the instructional program, all students could reproduce each procedure once completely without error. The immediate recall test was simply a second reproduction of those procedures. It is more difficult to explain why fluid aptitude was significantly related to immediate recall. It may be that the novelty and complexity of the Challenger task itself meant that higher levels of fluid aptitude were required even for immediate recall of learned procedures.

It is also difficult to explain the fact that, while fluid aptitude was highly correlated with delayed recall, the low-load treatment neither improved the delayed recall of the learners with lower Gf nor depressed the delayed recall of the learners with higher Gf, as it did in the case of near transfer. There was an equal amount of "forgetting" following each instructional method. It may be that a one-month interval in which there was absolutely no contact with the Challenger task overrode any of the benefits that the low-load treatment might have had for the learners with lower Gf. Most studies that measure delayed recall only allow a couple of days to elapse before retesting (e.g., Kamouri et al., 1986). In the case of this study, when the

task was presented one month later, it was almost a new learning experience and therefore the critical variable became, once again, fluid aptitude. The fact that the transfer tests were taken immediately after the immediate recall test, which provided additional practice of the procedures, may partly explain why the effect of the low-load treatment on learners with lower Gf was so apparent in the near transfer test.

The finding that the low-load treatment led to greater far transfer for all learners, regardless of fluid aptitude, seems to contradict the theory that instructional methods that provide support for cognitive processing depress the transfer scores of learners with high fluid aptitude. However, it is consistent with Snow and Lohman's (1984) conclusion that the pattern of disordinal interactions between general aptitude and instructional method becomes less apparent as the level of transfer increases. In the case of the present study, this finding should be viewed with caution because the scores on the far transfer test were extremely low, indicating that, for the amount of instruction and practice provided, the far transfer test was much too difficult. It may be that even those learners with high Gf did not have the time to acquire the necessary basic task-specific expertise to permit generalization to completely unfamiliar initial patterns of Challenger. In that case, whatever weak strategies the low-load treatment had provided may have proved more useful than any more general metacognitive skills.

On the other hand, this finding could lead to the hypothesis that when farther transfer of procedures is required after instruction, then external cognitive processing support during initial learning is beneficial for

all learners, regardless of fluid aptitude. However, this
hypothesis may hold only for farther transfer WITHIN a
particular domain of knowledge; it appears that fluid
aptitude or metacognition IS related to transfer of
knowledge BETWEEN domains (Corno & Mandinach, 1983; Snow &
Lohman, 1984).

5.3. Recommendations

The findings of this study add to the knowledge base
from which explanatory theories of aptitude-treatment
interaction, prescriptions for the design of instruction,
and directions for further research on cognitive methods of
instruction, are generated. Recommendations will now be
made in relation to each of these three applications of the
findings.

5.3.1. Explanatory theory of ATI

Without cognitive theories of learning, it would not be
possible to explain aptitude-treatment interactions,
particularly disordinal ATIs. In fact, it is only recently
that attempts have been made to draw together such findings
and to use cognitive theories of learning to explain them.
(Clark, 1989; Cronbach & Snow, 1977; Snow & Lohman, 1984).
The initial interpretations suggest that it is the
completeness of the cognitive processing support embedded in
an instructional method that is the critical factor in
producing disordinal ATIs. In order words, the extent to
which the outer instructional environment attempts to
compensate for deficiencies in the learner's internal
cognitive environment is what interacts with fluid aptitude.

The less the deficiency in the inner environment (i.e., the metacognitive skills of the learner), the less external support is needed. In fact, external support is dysfunctional for those who do not need it. The greater the deficiency in the inner environment, the more external support is needed.

The present study was undertaken in an effort to build up some confirmation of these new interpretations of previous ATI research, using a methodology that would control extraneous variables and maximize the effects of the critical variables. The treatments designed for use in the present study differed only in the amount of external support they provided for cognitive processing during the initial learning of procedures. The expected disordinal interaction with fluid aptitude was found, lending further support to the theory that ability to transfer knowledge is a function of type of cognitive processing during learning. The cognitive processing effects of the treatments used in this study were identifiable because the differences between the treatments were clear, the influence of prior knowledge was eliminated, and the computer was used as the instructional and testing environment.

The design of the study was perhaps a model for future ATI studies, in that it started from the baseline of what is already known from cognitive instructional theory and was very specific in its treatments and outcome measures. It is recommended that such specificity in treatment design and outcome measure be emulated and, indeed, refined in future studies, so that findings will make our current theory of ATI more robust. It is also recommended that greater differentiation of levels of transfer and levels of delayed recall be made both in the theory and research on ATI.

5.3.2. Prescriptions for the design of instruction

One of the main goals of ATI research is the prescription of appropriate instructional methods to accommodate the individual differences of learners. Cognitive theory has led us to view instruction as having two functions, the presentation of information and the provision of appropriate cognitive processing support for the learning of that information. Behavioral theory told us much about how to present information but nothing about how to support the learner's acquisition and subsequent use of that information. The focus of instructional research is now on what kind of, and how much, cognitive processing support to provide in instruction. There is also a drive to determine whether it is better to embed that support in existing subject matter or to provide separate instruction in metacognitive/learning skills for those who do not already possess and apply them (Derry & Murphy, 1986).

Whether or not it is better to embed or separate the cognitive processing support element of instruction, initially, we need a clearer definition of the instructional methods that compensate for deficiencies in learning skills. Unless the external support for information processing provided is sufficiently complete, workable, and relevant to the task, it will be an inadequate compensation even for those who need it (Clark, 1989). The problem is no longer one of either providing or not providing cognitive processing support; it is one of prescribing and designing instruction to incorporate the appropriate type of support in relation to the type of knowledge to be learned. Empirical evidence is being accumulated on the nature of the support provided by examples, analogies, models and

corrective feedback.

The present study indicates that when the task is procedural, the desired outcome is near transfer, and learners are deficient in fluid aptitude, then low-load instruction is best. Such low-load instruction should force learners to generate, test and evaluate their intuitive knowledge about the task, leading them eventually to construct and compile both the correct procedure and more general procedures related to the task. However, if the learners are high in fluid aptitude, they need little or no support for cognitive processing; rather, it seems that they need to be provided with complete information about the goals and operations of the task, a demonstration of the correct procedures, and opportunity to practice the procedures. Prescriptions for the design of instruction that would promote farther transfer of procedures within a domain of knowledge may be different; the results of this study suggest that more external support for cognitive processing is required by all learners in order for procedures to generalize to more novel problems within the domain. However, this is a very tentative conclusion and should be treated as a hypothesis for further research.

5.3.3. Directions for further research

There is a danger, that in adopting cognitive instructional methods across the board, instructional designers and educators will do a disservice to some learners. Learners with low metacognitive skills certainly need external support for cognitive processing, and researchers should continue to find, and identify the critical elements of, treatments that lead to greater levels

of transfer for learners who do not actively process
information under the more traditional behavioral methods of
instruction. However, the results of ATI research indicate
that many learners need very little external support for
cognitive processing, because they already possess the
necessary fluid or metacognitive aptitude to construct
meaningful and generalizable knowledge for themselves; all
they need is complete information about the task and the
procedures necessary to accomplish it. The results of the
present study support that theory, but in relation to near
rather than far transfer.

It is recommended that further research be conducted
using the Challenger task and the instructional programs
developed for use in this study. What should be modified
are the outcome measures. Multiple instances of items at
the same transfer level should be used to pinpoint the exact
nature and extent of transfer promoted by the treatments for
learners with different levels of fluid aptitude. This
would allow a more precise identification of the benefits of
each method for different learners and different transfer
goals. It would also be useful to extend the amount of
instruction provided.

The Challenger task is an ideal environment for the
study of ATI hypotheses due to its complexity and its
novelty. Being computer-based, it facilitates the
elimination of the "teacher variable", permits the
individualization of feedback, and allows for the collection
of detailed acquisition and performance data. Future
research might focus on analysis of the acquisition
protocols themselves, rather than inferring much of the
cognitive processing interpretations from the performance
data.

More generally, it is recommended that research toward the refinement of the construct of fluid aptitude and its measurement be conducted. The preferred label for fluid aptitude is now "metacognition", but a change in name alone will not help in the improvement of instructional methods. If we knew more about the components of metacognitive skill and the interaction of the those specific components with features of instructional methods, then we would be in a much better position to measure and explain ATIs in terms of cognitive processing. This would greatly increase our chances of providing more effective instructional methods for those who are not succeeding with existing instruction, and more efficient methods for those who are already succeeding.

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