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AN APPLICATION OF BRUNERIAN THEORY TO INSTRUCTIONAL SIMULATION: SPATIAL VISUALIZATION, FACTORIAL RESEARCH DESIGNS, AND WOODEN BLOCKS

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ABSTRACT

AN APPLICATION OF BRUNERIAN THEORY TO INSTRUCTIONAL SIMULATION: SPATIAL VISUALIZATION, FACTORIAL RESEARCH DESIGNS, AND WOODEN BLOCKS

Laura R. Winer

The present study maintains that Brunerian learning theory can provide the instructional designer with a useful theoretical framework for developing effective learning materials. Aptitude x Treatment Interaction research has also identified important learning variables in its analysis of individual differences and their interaction with different instructional techniques. Instructional simulations were thought to be an ideal vehicle for combining these two components. Simulations demand high-level learner involvement, central to the Brunerian model. Due to this involvement, learner aptitudes become critical in information acquisition. The manipulation of research design components, the experimental task, requires spatial visualization. Two self-instructional modules were therefore used: 1) an instructional simulation developed according to Brunerian learning theory; and 2) a traditional textbook approach. Both required approximately 1½ hours. Students in a graduate introductory statistics course were tested for spatial ability, grouped into high, medium, and low, and randomly assigned to treatment groups. They were given a pretest, an immediate posttest, a one-week delayed posttest, and a five week delayed posttest (midterm exam). The Brunerian simulation was found to be significantly more beneficial, especially for low spatial ability students, as predicted. Surprisingly, no sex differences were found in spatial ability. The two main conclusions from this study are the usefulness of isolating the significant aptitude required for a specific learning task and the relevance of Brunerian theory for instructional design.

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CHAPTER ONE

RATIONALE

In order to better understand the process of learning, in recent years instructional research has begun placing greater emphasis on individual differences in learner characteristics (Cronbach & Snow, 1977; Wittrock, 1977). Because of variation in learner characteristics--such as holist/serialist, field dependent/field independent, verbal ability, spatial ability--the same instruction will not necessarily affect all learners in the same way. When considering the effectiveness of instructional materials, it is necessary to identify which learner aptitudes may be most important for a specific learning task. This requires a careful instructional analysis (Dick & Carey, 1978) to identify such integral factors. The instructional designer must then design effective instruction for all learners using a given set of materials.

Unfortunately, the instructional designer has precious little useful research to draw upon in identifying, measuring, and implementing differing learner characteristics. Research has generally been piecemeal, with no integrative connections among various aspects of a particular instructional problem. The lack of useful instructional principles is derived both from the inherent complexity of the learning process and the fact that little is known about it. This problem is further compounded by the general weaknesses of much educational research methodology. To wit, researchers have failed to isolate productive variables and have generally failed to truly test instructional

effectiveness in any form. The most promising body of research investigating the correspondence between learner aptitude and instructional treatment has become known as Aptitude x Treatment Interaction research (ATI).

Although ATI research calls for a match between instruction and learner aptitudes, the cost of identifying individual learner characteristics and matching them to appropriate instructional materials is usually prohibitive. It would be far more useful to have instructional materials which would especially help those students weak in the abilities needed for each task without penalizing those who are strong. If such materials were created, they could then be used by all students, eliminating the need for the time-consuming, expensive, and potentially disruptive process of testing students and assigning them to different instructional treatments. A single, effective set of instructional materials is clearly the most desirable end product of an instructional design procedure. Rather than focusing on instruction that will satisfy the specific demands of individual constellations of characteristics, then, ATI research should primarily be concerned with determining which learner characteristics are involved in learning particular topics, and developing effective instruction for students with weak and with strong aptitudes in these areas.

As it is only within a theoretical framework that replicable prescriptive directives can be drawn, it is unfortunate that instructional design texts have not established themselves within a theoretical context. Guidelines for designing instruction generally do not offer specific

theoretical rationales for designing instruction or selecting media (Dick & Carey, 1978; Kemp, 1980; Romiszowski, 1975). In the education research literature, the stated "implications" for application of the findings appear to be afterthoughts rather than being a natural outgrowth of a coherent conceptual framework. Combined with internal and external validity problems, then, most ATI research has not permitted the development of general principles of instructional design. The emphasis in this thesis was expressly placed on external validity so that useful design principles could be derived. Furthermore, as will be discussed below, the study was placed within Brunerian theory to provide potential for integrative framework building. A high degree of internal validity was therefore also observed. The procedure followed was to identify a given task and analyze it to determine the primary aptitude involved in its execution. Then a set of instructional materials could be developed that would assist those learners who were low in the ability without hampering those with high ability.

The task chosen for analysis was the learning of two- and three-dimensional research design principles. These are usually taught using graphic representations. The most significant aptitude involved in this task had previously been identified as spatial visualization (Elmore & Vasu, 1980). French (1951) and Guilford and Zimmerman (1956) defined spatial visualization as the ability to mentally image movements, transformations, or other changes in three-dimensional objects. As spatial visualization is both easy to assess and a potent

indicator of success, it was both feasible and productive to study the interaction between instructional treatment and spatial visualization ability.

While the aptitude corresponding to the instructional task was somewhat obvious, the choice of an appropriate instructional medium was not so evident. After establishing that spatial visualization was an important factor in learning about research design, it was apparent that those students low in spatial visualization ability would encounter the most difficulty. As spatial visualization involves performing mental manipulations of three-dimensional objects, the instructional design task was to find a way of physically representing the abstract concepts involved. This would allow low spatial visualization ability learners to actually see the transformations they were required to perform.

This approach of concretizing a mental process finds theoretical support in the work of Jerome Bruner. Bruner's model of learning depicts three stages: enactive, iconic, and symbolic. The process of learning requires that the learner experience the concepts to be learned in the three representational modes--physical, pictorial, and symbolic--corresponding to the three stages. This theory seemed to offer the most potential for realistic and effective implementation in instructional materials. Bruner (1966b) outlined a theory of instruction which could operate as a framework for designing instruction. He delineates the development of the learning experience and gives examples of how subject materials can be structured to conform to his theory.

Unfortunately, there is little empirical evidence to show its effectiveness. One purpose of this thesis was to evaluate an application of Brunerian learning theory in a generalizable instructional situation.

Using Brunerian theory as a framework simplified the choice of an appropriate medium. Bruner stressed the importance of learner interaction with abstract concepts and the effectiveness of providing physical models to achieve this. Physical models are a defining characteristic of simulations. Simulation is a medium which involves the manipulation of a model of some concept or system. Instructional simulations, by requiring the manipulation of a representation or abstraction of reality, appear to meet the Brunerian instructional criteria with minimal need for alteration on the instructional designer's part. Unfortunately, the study of simulations has also suffered from a lack of hard evidence regarding its effectiveness and appropriateness. Although Reiser and Gerlach (1977) were unable to come to any conclusions about the effectiveness of instructional simulation games, they cast most of the blame for this on the quality of research that has been done in the area rather than on the inherent qualities of simulation games. Cruickshank and Mager (1976) also fault the lack of a theoretical base to simulation games design as a contributing factor to the disorganized state of present knowledge. Bruner's "theory of instruction" could serve as this missing framework.

This thesis attempted to integrate several areas of inquiry which seem to be logically related. Brunerian theory provides a theoretical rationale for both the design of simulations and the teaching of

abstract concepts such as research design principles. As spatial visualization has been implicated as an important factor in learning these principles, the interaction of students' ability in spatial visualization and the instructional treatment they received was also investigated. An instructional simulation on research design principles was designed according to Brunerian learning theory. Students' spatial visualization ability was assessed and studied in interaction with simulation and traditional instructional materials. It was expected that there would be an interaction between spatial ability and instructional treatment, with low spatial ability students benefiting from the applied Brunerian treatment and high ability students performing equally well under both treatments. It was also expected that all students would benefit from the applied Brunerian treatment because of the validity of the theoretical model upon which it was based.

CHAPTER TWO

REVIEW OF THE LITERATURE

The three major components of the study, Brunerian learning theory, instructional simulations, and spatial visualization, have not been previously integrated within either theoretical or instructional contexts. It is therefore necessary to examine each in isolation, although areas of overlap and agreement will also be identified. Finally, how they might be combined to assist in the design of instructional materials will be outlined.

Bruner's Three-Stage Theory

Although much of Bruner's work has been on the cognitive development of children, the theoretical base which has resulted warrants investigation in relation to adult learners. His three stages, enactive, iconic, and symbolic (Bruner, 1964, 1966a, 1966b), outline the initial development phases children pass through on their way to intellectual maturity. But these stages are not like a snake's skin to be shed after each new representational stage becomes operative; rather, each builds upon the one before. The stages appear in children in the order of enactive, iconic, and symbolic, with each dependent upon the earlier one for its development. However, each stage remains relatively intact throughout life and continues to influence learning when the more advanced stage(s) make their appearance.

This developmental process is, or at least should be, reenacted each time some new piece of knowledge is learned (Bruner, 1966b). In

order for any learner, whether adult or child, to learn effectively, each mode of representation should be involved.

A mode of representation is a way of translating experience into a model of the world (Bruner, 1966b). The first mode is the enactive one. This involves a set of actions appropriate for achieving a certain result and is based upon a learning of responses and forms of habituation. This provides the learner with a physical representation, either external, if something has been built, or internal, if the learner can mentally review those actions. For example, when teaching the expansion of quadratic expressions, the first step can be having the student "build" the expressions with different shape blocks of wood representing the different components of the expression. This provides both a set of actions for the learner to review and a physical referent for the notational symbols when they are introduced.

The second mode is iconic; it consists of a set of summary "images" or graphics that stand for a concept or thing without defining it fully. It is principally governed by principles of perceptual organization and economical transformations in perceptual organization (Attneave, 1954). To continue the example from above, in this stage the learner would refer to his/her perception of the blocks, i.e. a pictorial representation of the physical objects. This stage can be achieved either by having the learner draw the representation or by providing him/her with a picture of the concept involved.

The final mode of representation is symbolic. In this mode there are arbitrary symbols which are remote in reference. Symbol systems

generally have the ability to produce or generate new statements or propositions and are governed by rules or laws for forming and transforming a set of symbolical or logical propositions. When the quadratic expressions mentioned above have been physically and iconically represented, it is then possible to introduce mathematical notation, in itself an arbitrary representation of the concept, but within the context established having not only meaning but potential for further manipulation beyond that of the physical example.

According to Bruner (1966b), any domain of knowledge or problem within it can be represented via these three representational modes. But Bruner (1966a) points out that each of these ways of modeling reality is limited. The enactive mode is constrained by the physical requirements of adaptive action and the human neuromuscular system. The iconic mode is constrained by visual, auditory, and haptic space. Even the symbolic mode is constrained by human limitations on mastering symbolic systems based on rules of hierarchy, predication, causation, and modification. The fact that each mode has its limitations argues strongly for the importance of incorporating each into the learning process, no matter what the age of the learner. The three modes can be conceived of as a pyramid, with enactive providing the broad base, iconic the intermediate level, and symbolic the pinnacle. Each obviously has unique potential for contributing to learning, but none is sufficient.

Aside from its theoretical interest in terms of how knowledge is handled by the human cognitive system, the three-modal theory has

serious implications for instruction.

> Instruction consists of leading the learner through a sequence of statements and restatements of a problem or body of knowledge that increase the learner's ability to grasp, transfrom, and transfer what he is learning. In short, the sequence in which a learner encounters materials within a domain of knowledge affects the difficulty he will have in achieving mastery. (Bruner, 1966b, p.49)

The meaning of "statements" should not be restricted to verbal statements, but should be interpreted as any representational form of an idea along the continuum from concrete to abstract.

Because of the importance of the sequence in which a learner encounters novel material (see also Cattell, 1971), it is critical that curricula should be tailored to the learner's existing mode of representation. For example, if one is dealing with learners whose mastery of the symbolic system is not fully developed, one should make sure that the first encounter with the new material is not in symbolic form. This does not mean, however, that the first two stages should be neglected once the learner is competent in the manipulation of the representational system being used.

One example of how this theory was translated into action comes from Bruner's experience in teaching the expansion of quadratic expressions to eight-year-olds.

> The object was to begin with an enactive representation of quadratics--something that could literally be "done"

> or built--and to move from there to an iconic representation, however restricted. Along the way, notation was developed and, by the use of variation and contrast, converted into a properly symbolic representation. (Bruner, 1966b, pp.64-65)

Sequencing instruction in this fashion recapitulates the process of discovery of the world around us. There is no reason to suppose that adults would benefit any less from this sequence than children. The only potential point of departure would be if the adult learners have already mastered the symbolic code they will be using eventually (be it language, mathematics, or musical notation), it is possible, perhaps desirable, to give them a symbolic representation of the problem before going through the enactive and iconic stages. This would serve to provide the learner with an instructional goal and to maintain interest. Most adults would not sit and "play with blocks" without seeing the point. Thus, because most adults have mastered the symbolic system of language, they can first learn something from such an introductory presentation. The subsequent instructional activities would then fill in the gaps left by this purely verbal instruction.

To effectively implement the Brunerian model in a variety of different contexts, the instructional designer must first identify at what developmental level the learners are already competent. Then s/he must carefully weigh the need for either explicitly providing concrete instructional references or inducing the learners to provide their own. In a case where the learners' prior knowledge is sufficiently

high (and what constitutes "sufficient" must be determined by an instructional analysis) or a concrete referent is self-evident, the instruction does not have to explicitly lead the learner through the stages. If, however, the learners do not have the capability of generating an enactive and/or iconic representation of the iconic or symbolic concept, the instruction must, in the interests of efficiency and effectiveness, provide a structure which will do this for the learner.

One instructional form which allows for manipulation of concrete models of abstract concepts is simulations. Although they have not, to my knowledge, been specifically linked to Brunerian theory, they seem to have an inherent capacity to offer the kind of learning experience which Bruner recommends.

Instructional Simulations and Games

Simulations require the learner to manipulate a representation or abstraction of reality. Because they demand manipulation, they ensure that the learner will be provided with an enactive representation of the concept to be learned. It is easy to incorporate an iconic stage by having graphic or pictorial representations and most formal learning results in representation at the symbolic level. Simulations, therefore, follow Bruner's theory with only minimal structural impositions. This instructional alternative has great potential as a means of turning Bruner's theory into educational practice.

Since there are no generally accepted definitions of simulations, games, and simulation/games, the first step in this discussion must be to define our terms. Simulation has been defined by Seidner (1978) as the dynamic execution or manipulation of a model of some object system. An educational simulation entails abstracting certain elements of social or physical reality such that students may interact with that simulated reality. A game has players operating within an agreed set of rules and competing for some reward (Megarry, 1978). A simulation/game, by logical extension, is a game within the context of an abstraction or representation of some aspect of the real world (Reiser & Gerlach, 1977).

The history of simulations, games, and simulation/games in learning does not seem to have progressed beyond phase three of Boocock and Schild's (1968) "capsule history". The three phases they identified are: 1) acceptance on faith; 2) post-honeymoon; and 3) realistic optimism. There is still little empirical evidence to support the use of this instructional technique within education (Dukes & Seidner, 1978; Megarry, 1978, Reiser & Gerlach, 1977), but the intuitive reaction of many educators that simulations, games, and simulation/games are valuable additions to instructional menus continues to sustain the optimism.

One problem in collecting supporting empirical evidence is the state of disorganization in which the existing body of knowledge about instructional simulations and games rests (Cruickshank & Mager, 1976). There are several reasons for this state of affairs. The

first is that much of the work has been done with reference to specific disciplines only. As interdisciplinary communication tends to be limited, there has been little combined effort in going beyond the pragmatic approach that has predominated the development of instructional games and simulations to developing a theoretical framework. Secondly, few educators devote a substantial part of their time to this area even within their own disciplines. Demands for research of their own fields compete for the scarce resources available. A third reason that contributes to the dearth of "hard" evidence is the transient nature of many students of instructional simulations and games. There have been many one-time researchers attracted by curiosity; few have devoted much energy over an extended period of time.

Several of these problems may be inherent in the field, but certainly at least some of them can be resolved. In their 1976 article, Cruickshank and Mager made an appeal for developing an organized base of knowledge. To this end they proposed three steps toward theory building: 1) clarifying the vocabulary; 2) establishing the relationship of simulations and games to other instructional alternatives; and 3) increasing via systematic research the knowledge about the effectiveness of games and simulations as instructional alternatives. One aim of this thesis was to help in the third step.

Although this study utilized an instructional simulation which had no game element, the paucity of research on pure simulations and the common grouping of simulations and games into "simulation games" requires that research on the general instructional tool be considered.

In a review by Reiser and Gerlach (1977), they identified five student-related variables that most research has been concerned with: 1) interest; 2) attitudes; 3) feelings of efficacy; 4) acquisition of knowledge; and 5) intellectual skills. Each is reviewed below.

There has been some confusion in the research on interest generated by simulation games between interest in the subject matter represented and interest in the instructional medium per se. Edwards (1972) is one of the few studies to have found a simulation game to increase student interest in the subject matter. In measures of student interest most other studies indicated that simulation games had little or no effect on student interest in the subject matter.

Results concerning the effects of simulation games on attitudes are equally unclear. Some studies (Livingston, 1971, 1972) indicate that simulation games have a positive effect on student attitudes while others (Boocock, 1968; Kidder & Aubertine, 1972) report that they do not. There does not seem to be any consistent pattern to the results.

Equally varied are the results of studies of how simulation games affect students' feeling of efficacy or belief in their ability to control their own destiny (Reiser & Gerlach, 1977). This has been explored primarily within the context of politics and business simulation games. Once again Reiser and Gerlach (1977) report an inability to come to any conclusion because of the inconsistency of the data.

Many studies have been done on the effect of simulation games on acquisition of knowledge. Knowledge, as defined by Bloom, Englehart,

Furst, Hill, and Krathwohl (1956), is the recall and recognition of an idea or phenomenon. Studies typically compare simulation games to traditional instruction and most of the results indicate that students acquire approximately the same amount of knowledge in both (Anderson, 1970; Chartier, 1972).

A second level of Bloom et al's taxonomy that has been investigated is intellectual skills, defined as an individual's ability to apply knowledge to new problems. Many studies in this area have been in the field of business and again the results are ambiguous. The skill often most affected by participation in a simulation game is the ability to play the game itself (Fletcher, 1971; Schild, 1968).

The non-positive nature of the results of much of the research on simulation games is attributable to several factors. Simulation games have typically been designed in an unsystematic fashion, with no prior specification of behaviors (which makes identification of appropriate dependent measures difficult), and, perhaps most important, with no specific theoretical underpinnings. As Bruner (1966b) ennunciates, games (in the broad sense of simulation games) can be invaluable aids in transforming the learner from a passive recipient of knowledge to an active participant in the learning process. Romiszowski (1975) also mentions simulation games as generally involving students in the learning task, both intellectually and emotionally, more than other available instructional techniques. Bruner (1966b) specifically mentions "games that incorporate the formal properties of the phenomena for which the game is an analogue. In this sense, a game is like a

mathematical model--an artificial but often powerful representation of reality" (pp. 92-93). The kind of game that Bruner is refering to is, in essence, a simulation. As most of Bruner's work was done with children, the motivational aspect of games would be very important. When dealing with supposedly self-motivated adult learners, however, that aspect would be less necessary, and a game structure would not have to be artificially introduced if it were not appropriate to the content or would make the simulation harder to use, e.g. a self-instructional package which had a game needing several players could pose serious logistical problems.

Another cause of the inconclusive nature of many of the results is the failure of researchers to examine the factors that might contribute to or interact with the effectiveness of simulation games, either in general or with relation to the specific task at hand. Romiszowski (1975) identified two types of analysis of a learning problem which are required before designing a simulation or game. The first is an analysis of the real phenomenon under study so as to be able to design a valid model. The second is an analysis of the learning task and difficulties to determine how much simplification of the model or break-down into special exercises would be appropriate.

Simulations obviously have potential as vehicles for providing learners with the interactional type of instruction recommended by Bruner. The Brunerian three-stage model of learning can provide a useful framework within which to design simulations. It provides a sequence for activities, and emphasizes the important interactions

between the learner and the materials that must occur for effective learning. It was used in this thesis as a model for designing the simulation.

If a simulation follows the Brunerian approach, it is important to isolate the abstract component(s) of the learning task and establish a physical referent for each. In the specific case of research design, spatial visualization has been identified as a key factor in the abstract conception of the principles involved (see discussion following). Once this has been done, it is possible to design the instructional materials to compensate for learners' weaknesses. This step of isolating perceptual as well as cognitive elements of the learning task is necessary if the simulation is to be able to provide the enactive and iconic representations required for learning.

Spatial Visualization Ability

Spatial visualization ability has been defined by both Guilford and Zimmerman (1956) and French (1951) as involving imaginary movements, transformation, or other changes in three-dimensional objects. This ability seems to be required in various perceptual-cognitive tasks involving the mental transformation of visual images, and has been shown to be important for college math (McGee, 1979). Fennema and Sherman (1977), Fennema (1975), and Sherman (1967) also found spatial visualization to be logically related to the content of mathematics.

With more specific reference to statistics, it is important for students to be able to visualize research designs (see Kulhavy, Schmid,

and Dean, 1977). When studying complete factorial designs, this can be done most easily by imaging a number of blocks, each representing one group, arranged by factor and level so as to form one or more large cubes. The number and arrangement of these cubes depends upon the type of design being used in the study under consideration (see Drew, 1976). This mental model is especially useful when dealing with three-factor designs. The most precise method of referring to specific groups is by a system of coordinate notation as used in graphing. These coordinates are derived from each factor, and each imaginary block represents a unique combination of the three factors. One can mentally separate the larger cube into layers to differentiate between groups and conceptualize statistical comparisons to be made.

The intellectual leap from a verbal description of a factorial design to its conceptualization in terms of a set of coordinates labeling its component cells is one that can be assisted by the mental manipulation of three-dimensional objects. This task satisfies French's and Guilford and Zimmerman's definition of spatial visualization. In support of this connection, Elmore and Vasu (1980) investigated the effects of a number of variables, including spatial ability, on statistics achievement. Spatial ability was found to account for more variance than any other variable; there was an r of .442 ($p < .0001$) between the spatial ability subtests and statistics achievement.

There are two distinct components of statistics, the mathematical or computational and research design. The mathematical component is not central to the conceptual understanding of statistical principles,

although it can be helpful if one knows the procedures. What is critical is a grasp of statistical principles and an awareness of their applicability. This requires an understanding of research design principles which are distinct from mathematics. As spatial visualization has been implicated as an important factor in the conceptualization of design principles (Elmore & Vasu, 1980; Kulhavy et al, 1977), instruction should be designed to compensate for students with low spatial ability without impeding high spatial ability students.

Processing differences. What causes the individual differences in spatial visualization is a question which has not yet been answered definitively. Snow (1978) identified four different forms or sources of individual differences in information processing: 1) parameter differences (p-variables) are differences between the individuals on particular steps or components (e.g. short-term memory capacity); 2) sequence differences (q-variables) are found when learners perform the same steps but in a different order; 3) route differences (r-variables) occur when qualitatively different steps are used by different learners to perform the same task; 4) summation or strategic differences (s-variables) are gross differences in the assembly and structure of program systems.

There has been no agreement on the classification of spatial ability individual differences as one type of variable. Anderson (1967) considered it "probable" that learners with different levels of proficiency on the same task were employing different skills in performing the task; r-variables would be involved if this is the

case. However, Egan (1979) broke down the performance of spatial test items into three distinct steps: 1) visual coding; 2) an operation is performed to transform the code; 3) the transformed representation is compared with another visual stimulus. In Egan's opinion, all learners seem to use the same process in answering spatial test items, with only the rate changing. This would mean that p-variables were involved, with speed of execution being the parameter. It is suspected, however, that qualitative factors play a larger role. The hypothesized ATI of this study would lend greater credence to these qualitative differences.

Sex differences. When assessing learners' spatial ability, researchers have found that males appear to be "inherently" superior to females (Backman, 1972; Buffery & Gray, 1972; McGee, 1975). This has important implications for instruction as it may be that differential instruction based on sex might be necessary for learning tasks which require spatial visualization. There have, however, been studies which have not shown the dramatic differences that the above studies did. In Fennema and Sherman's (1977) study, even though the males tended to score higher in all cases, the differences were significant in only two of the four schools tested. Elmore and Vasu (1980) found that male students scored significantly higher than female students on only three of the five tests of spatial ability used. There is also evidence that the sex variable interacts with age, an additional factor. For example, Harris (1978) and Maccoby (1966) found that sex differences did not reliably appear until puberty. Backman (1972) also found that differences between the sexes apparently become more

marked with age. It seems, therefore, that the "inherent" ability is subject to sociological determinants.

The question of whether spatial visualization ability is a "given" or somehow acquired over time has not been answered. Salkind (1976) and Salomon (1974) both found that it was possible to improve spatial performance with controlled practice and training. Salomon capitalized on the internalization potential of filmic schematic operations by showing subjects a film which repeatedly illustrated the unfolding of solid objects, e.g. cubes, into flat surfaces. Transfer tests showed that experimental subjects were superior to control subjects in spatial visualization and visual manipulation.

Obviously, the origins of spatial visualization ability are unclear; the nature/nurture controversy has not been settled here nor anywhere else. What is clear, however, is that spatial visualization is an ability which facilitates the learning of statistics. The problem for instructional designers, therefore, is to design instruction which will benefit those people who, for whatever reasons, are not high in spatial visualization without hindering those students who are already strong. Any instructional material created must consider how spatial visualization will interact with it. The consideration of how student aptitudes interact with instructional treatments has been investigated in what has become known as Aptitude x Treatment Interaction research. This broad area includes many aptitudes. General findings as well as those with specific relevance to this thesis will be considered next.

Aptitude x Treatment Interaction Research

Cronbach and Snow (1977) defined the educational research task as formulating principles by which the adaptation of instruction to each student can be made systematic and productive. This, of course, leads one to the consideration of individual differences, with the problem being to locate interactions of individual differences among learners with instructional treatments, i.e. Aptitude x Treatment interactions. Snow (1978) defined aptitudes, within an educational context, as being "student characteristics that predict response to instruction under a given instructional treatment" (p. 227).

The problem with Aptitude x Treatment Interaction (ATI) research is that there has been no consistent pattern of results. Surveys of ATI research by Bracht (1970), Bracht and Glass (1968), and Cronbach and Snow (1969, 1977) found few instances of significant ATI effects. This does not mean, however, that ATI research should be given up yet; rather it implies that researchers must refine their methodologies and isolate more productive dimensions of aptitudes in interaction with learning of different material (Bracht, 1970). As Ausburn and Ausburn (1978) point out, much of the failure of ATI research to yield practical instructional design principles results from the lack of precision in isolating learner, task, and instructional variables for study and the failure on the part of many researchers to establish a sound rationale for their assumptions about interactions.

Snow (1970) offered two heuristic models for thinking about ATI relations, compensatory and preferential. In the compensatory model,

the environment or treatment compensates for the learner's deficiencies. The treatment functions as an "artificial" aptitude, aiding the learner in performing some necessary processing function(s). The preferential model matches the learner and environment; success here depends on the degree to which the instruction is tailored to the capabilities of the learner and how well the learner likes the environment. The two models are not mutually exclusive as each has its particular area of emphasis; the compensatory model emphasizes cognitive factors while the preferential emphasizes affective factors.

In concurrence with Snow's model but with different terminology, Ausburn and Ausburn (1978) speak in terms of an instructional treatment supplanting for learners a process that they are unable to perform, a process necessary to the learner/task link. Their model has two supplantation approaches, compensatory and conciliatory. In compensatory supplantation, the instructional treatment compensates for the learner's deficiencies by doing for the learner what s/he cannot do. In conciliatory supplantation, the method of presenting the task is altered so as to remove requirements causing difficulty.

Cronbach and Snow (1977) added a third heuristic model to Snow's (1970) earlier two. They introduced remediation, an instructional model in which specific holes in a student's knowledge are filled in. They recommend remediation rather than compensation for dealing with weaknesses in general skills such as reading ability.

According to Cronbach and Snow (1977), the premise of ATI research is that the instructional conditions determine what kind of person will

learn most rapidly. But because the relationship between aptitude and learning is not linear over time, there are implications for when data should be collected. There are always going to be idiosyncratic reactions from some learners, and the level of prior knowledge may have implications for the ability to acquire new information. But within a given level of prior knowledge and counting on statistical procedures to control for idiosyncrasies, the question of when a true measure of learner ability can be obtained still remains. "If a fast start implies talent, then teachers and aptitude tests ought to place much weight on early data. If the tortoise often overtakes the hare, it is bad policy to make early decisions." (Cronbach & Snow, 1977, p. 123) It still rests upon the researcher to evaluate the individual merits of the specific case and make decisions about what is meaningful and/or possible; obviously, some situations require fast results while others can wait for the slower but potentially more beneficial long-term results.

As the range of aptitudes lumped together under the ATI research umbrella is far from homogeneous, at this point it would be useful to consider only that aptitude with relevance to this thesis--spatial visualization.

Spatial ability in ATI research. In spite of the large amount of ATI research, little has been done on spatial visualization. As stated earlier, spatial visualization involves imaginary movements, transformation, or other changes in three-dimensional objects. However, as Cronbach and Snow (1977) point out, treatments designed to capitalize

on spatial ability generally present information diagrammatically or require reasoning about or learning from diagrams. It is quite probable that many of the studies that have been carried out have not truly involved spatial visualization but rather some unnamed aptitude of visual reasoning. This would account for the high percentage of studies with results of "no significant differences" (Bracht, 1970; Cronbach & Snow, 1977; Sternberg & Weil, 1980). There are also studies which test for one form of spatial ability but use another in the learning task. For example, Delaney (1978) used tests which require the transformation of images when the task in his study required subjects to produce images. This inconsistency in methodology also contributes to the inconsistency of the results. From this inconsistency, however, it should not be inferred that spatial visualization ability is inconsequential in all learning. As Elmore and Vasu (1980) found, spatial visualization is an important ability for learning statistics. What is needed, then, is research that truly investigates how spatial visualization interacts with learning material which requires this ability.

Sternberg and Weil (1980) attempted to demonstrate an Aptitude x Strategy interaction in linear syllogistic reasoning. Based on the work of Gavurin (1967) and MacLeod, Hunt, and Mathews (1978), they hypothesized that the efficiency of each of the four alternative strategies for solving linear syllogisms (linguistic, spatial, algorithmic, and mixed) would depend on the subjects' pattern of verbal and spatial abilities. They found that it was possible to train

at least some subjects to use a visual representation or algorithmic strategy and that the algorithmic strategy had the greatest overall efficiency. They attributed the lack of interactions to the possibility that there were subjects in particular groups who did not follow the instructions. When they regrouped subjects according to strategies actually used, a pattern developed suggestive of the sought-after interaction between student verbal and visual abilities and strategy used.

Delaney (1978) investigated the interaction of individual differences with visual and verbal elaboration instructions in the learning of foreign-language--English word pairs. His hypothesis was that instructions in a mnemonic strategy would interact with measures of the principal ability involved in the application of that strategy. Subjects were assigned to one of four groups based on measures of verbal fluency (VF) and visualization/spatial ability (VS): high VF, high VS; high VF, low VS; low VF, high VS; low VF, low VS. Subjects were then randomly assigned to one of three groups: control, visual elaboration, or verbal elaboration. For high VF subjects, the verbal elaboration led to more correct responses than the visual elaboration with the reverse being true for low VF subjects, leading to a disordinal interaction. There was no interaction, however, between VS ability and instructional condition.

In Delaney's study, the task under consideration was a verbal one. With a verbal task, high verbal ability learners will be able to contribute to the learning process sufficiently to counter less

effective instructions. However, as discussed earlier, much of statistical research design involves spatial abilities. With a spatial task, then, a spatial instructional method is imperative--it will help those with low spatial abilities without harming those students who are high in spatial ability. One can infer from this study that task characteristics must be considered when deciding what learner abilities are appropriate to measure. Those students at a high level of learning task ability will not need compensatory instruction; the educator's task is to provide the necessary compensation for those who do need it.

The above research indicates that spatial ability, instructional treatment, and task characteristics do affect each other. When one considers that in general it is cognitive factors which are the concern of instructional designers, it would seem that the compensatory model of Aptitude x Treatment Interactions has the greatest potential for making mastery learning a realizable goal. With particular reference to research design, it has already been shown that spatial ability contributes significantly to mastery. The task is, therefore, to isolate the ability tapped in a learning situation, identify an instructional treatment that will provide compensation for those who need it without hindering those who do not, and verify that the interaction functions as predicted.

Implications of the Research

It is apparent from the above review that there is much to be done in building a theoretical basis for designing instructional

simulations. The works of Bruner offer a framework which could be built upon and formalized as a structure for instructional design. Simulations seem to have the greatest potential of available instructional alternatives for implementing this theory, but this implementation must be accompanied by careful study in order that the technique may be refined and better applied. Finally, the ATI research with spatial visualization has by and large failed to isolate tasks which truly involve spatial visualization. With a task such as the learning of research design principles at hand, a study exploring the interaction of spatial visualization and instructional method could be attempted. Again it seemed that simulations, by inherently requiring the manipulation of a model, were the obvious bridge between the problems associated with the mental manipulations necessary to research design and low spatial visualization ability students. Additionally, simulations require minimal structuring to have them conform to Bruner's three stage model. This study was designed to ascertain the validity of these relationships.

CHAPTER THREE

METHOD

Design and Subjects

Two factors, spatial visualization ability and instructional strategy, were isolated in this study. Three levels of spatial ability were determined by subjects' scores on two standardized tests. Instructional strategies employed either a standard textbook method or a Brunerian developmental method. A pretest, immediate posttest, and delayed posttest were administered. The design was thus a 3 spatial ability (high, medium, and low) x 2 instructional strategies (standard vs. applied Brunerian) x 3 test position (pretest, immediate posttest, and delayed posttest) mixed model (see Figure 1).

The high, medium, and low spatial ability subject groups were each randomly divided into two groups. Subjects were 34 students in the introductory statistics course of the Educational Technology graduate programme at Concordia University.

Materials

Two tests were used to rank subjects on their spatial visualization ability. The SVT of the Dailey Vocational Tests measures the ability to visualize objects presented two-dimensionally in three dimensions. The items require the subjects to match the edges of a folded and unfolded figure. Part VI of the Guilford-Zimmerman Aptitude Survey consists of a series of mental rotations of clocks according to arrows indicating the direction and amount of rotation required. The subject must pick

Figure 1

Experimental Design

Spatial ability	Instructional strategy: Applied Brunerian	Instructional strategy: Traditional
high	pretest/ n=5 immediate posttest/ delayed posttest	same n=5
medium	same n=6	same n=6
low	same n=6	same n=6

out the final position of the clock from five alternatives.

Two different instructional strategies were employed. The first was print-based and taken almost entirely from Chapter Two of Drew's Introduction to Designing Research and Evaluation (1976). Minor modifications were made by the author to ensure that both sets of materials covered the same subject matter. The print material provided definitions of terms and a discussion of how one represents two- and three-factor research designs. Embedded questions appeared throughout the material.

The second strategy made use of the same printed introductory material as the first. The difference was that instead of printed embedded questions, a simulation designed by the author based on Brunerian learning theory principles was used. The simulation consisted of 16 research designs presented as word problems, both two- and three-factor. The subjects were required to construct the factorial design using the wooden building blocks. One side of each block was covered with blue acetate for marking on with a felt pen. They were then required to draw the design using the blocks as the model and answer three questions about various aspects of it (e.g. number of between and within factors, number of different groups required, etc.). (All materials are available from the author on request.)

The pre- and posttests consisted of 10 additional design descriptions (five per test) similar to those covered in the instructional materials. Subjects were asked to sketch out the design and answer the same type of questions as those appearing in the instruction. To

generate the tests, a pool of two-factor, three-factor, and four-factor designs was created, from which the pre- and immediate posttest questions were randomly selected. Thus two parallel forms were used. The four-factor designs were included to assess the ability of students to transfer knowledge used on "simpler" designs to more complex configurations.

A block counting test from the Stanford-Binet Intelligence Scale (Terman & Merrill, 1973) was given to provide a measure of how the different treatments affected spatial ability.

In an attempt to isolate which of the four individual differences variables--parameter, sequence, route, or summation--(Snow, 1978) was involved, subjects were asked to write down as a separate homework task their mental actions (solution strategies) as they solved a three-factor design problem similar to those on the pre- and posttests. Questions appeared on the left side of each page with the right side having space for the answers. As well, blank scratch space was available underneath each question.

Procedure

The spatial visualization tests were administered in the first class period of the fall term. Counterbalancing was employed by randomly dividing students into two groups, having them write in separate classrooms, and giving one group the Dailey test first and the other the Guilford-Zimmerman. A Pearson product moment correlation coefficient was calculated between the scores on the Dailey and Guilford-Zimmerman tests to assess the degree to which these tests measured the same

construct. A score of .65 was obtained, statistically significant at the .01 level. Both tests purport to measure the same theoretical construct (Dailey, 1965; Guilford & Zimmerman, 1956), and this datum provided further support for this assumption. The scores from the two test were combined and learners were assigned a group ranking and divided into high, medium, and low spatial ability groups. Subjects from these three groups were then randomly assigned to one of two groups, one received print instructional materials (traditional) and the other received the simulation (experimental).

The pretest, which took 20 minutes, was also administered during the first class under the guise of general information gathering for the course. The math pretest from Minium (1978) was given to the subjects to complete at home and was collected in the second period.

All subjects signed up for a session outside of class time during the first week. The simulation subjects were run individually, using the materials in a quiet, well-lit room which contains 11 carrells for individual study. The print subjects were also run individually, although on some occasions there were several subjects working through the materials simultaneously. All subjects were allowed as much time as they wanted, but a record was kept of the time spent with the materials. After the subjects had finished going through the materials, they were given 20 minutes to complete the immediate posttest.

The delayed posttest (identical to the pretest) was administered at the beginning of the second class period witn students again allowed 20 minutes to complete it. A questionnaire regarding subjects' own

perceptions of their spatial ability and their attitudes toward the material they used was then administered. After the delayed posttests and questionnaires had been collected, subjects were given their scores on both spatial tests as well as the class mean and ranges.

Subjects were given the strategy explanation task involving a three-factor problem to complete at home during the second week.

The 50 second block counting test (Terman & Merrill, 1973) was given during the third class period. The 10 item configuration was presented on a screen via an overhead projector. A test item prior to the presentation ensured that the stimuli were clearly visible to all learners in the room. A long-term delayed posttest (with questions from the immediate posttest) was given in the midterm exam.

CHAPTER FOUR

RESULTS

In the first analyses, the moderator and control variables which had been accounted for in the design were examined. The next stage focused on the interactions of the primary variables. Finally, analyses were performed on the data relating to the affective nature of the materials.

Controlled Variables

Due to the complexity of the natural classroom environment, a number of variables had to be controlled or accounted for to preserve internal validity.

Counterbalancing was employed in the administration of the two spatial tests. To assess the effectiveness of the counterbalancing, a dependent t-test was performed. No difference was found.

Sex is traditionally a significant variable in studies involving spatial visualization ability. Random assignment of sex to groups was expected to overcome composition bias, but not overall sex differences. However, no differences were found with t-tests in either comparison.

Another factor that was considered to have possible significance in performance of the learning tasks was math ability. This was eliminated when no significant differences were found between the treatment groups on scores on the math pretest given (Minium, 1978). Math ability was further discounted as being a significant factor in learning the materials when correlations run between math ability and pretest and posttest scores were very low.

In order to establish what effect, if any, math anxiety (i.e. subjects' perceptions of their math abilities) had on learning the materials, the two questionnaire items related to perceptions of math (arithmetic and algebra) and geometry were analyzed. Geometry ability was questioned separately because of the inherently spatial characteristics of it and the task to be learned. The correlations between subjects' perceptions of their math ability and pretest, immediate test, and delayed posttest scores were not significant. However, the correlation between perception of geometry ability and delayed posttest scores was .44, statistically significant at $p < .01$. The correlation between perception of geometry ability and delayed posttest scores was only marginally significant ($r = .26$, $p < .09$). These correlations support the classification of the task as inherently spatial.

As this study involved the learning of logically familiar but specifically novel material, one would expect that prior knowledge could be a potent factor. Prior knowledge was assessed from the pretest scores. The two treatment groups were compared and no significant difference was found in group composition. Subjects were then regrouped according to pretest scores as high, medium, or low prior knowledge. Gainscores were calculated by subtracting the pretest from the immediate and delayed posttest scores (see scoring procedure and results below). Means and standard deviations are listed in Table 1. A Kruskal-Wallis test was performed on these data and yielded insignificant results for the effect of prior knowledge on subsequent performance by all subjects.

TABLE 1

GAINSCORES FOR IMMEDIATE AND DELAYED POSTTESTS

TEST POSITION	LEVEL OF PRIOR KNOWLEDGE	SIMULATION $\bar{X}$	SIMULATION S.D.	TRADITIONAL $\bar{X}$	TRADITIONAL S.D.
Immediate Posttest	High	.1	4.56	-2.1	1.59
	Medium	2.3	1.72	1.2	2.68
	Low	3.3	4.87	.4	1.34
Delayed Posttest	High	3.3	3.25	1.7	2.36
	Medium	4.2	1.60	3.2	2.11
	Low	4.4	2.22	2.9	1.14

Thus, because prior knowledge and spatial visualization were significantly correlated ($r=.42$, $p<.01$), and prior knowledge was identified as the less potent predictor of achievement despite its content similarity, only spatial visualization was considered in subsequent analyses.

Subjects were permitted to spend as much time as they wished studying the instructional materials. A record was kept for each individual. In order to determine if time spent with materials was a factor, the two groups were compared. No significant differences were found.

Achievement Tests

The pretest, immediate test, and posttest each consisted of five problems with three questions per problem worth a total of 18 points. Test performance was scored by number correct. The long-term delayed posttest was not identical in format and was therefore analyzed separately and will be discussed later.

Raw scores. A 2 Treatment x 3 Spatial Visualization x 3 Test Position ANOVA was performed on the raw scores for the three achievement tests. Means and standard deviations appear in Table 2. All three main effects were statistically significant, Treatment, $F(1,28)=11.90$, $p<.002$, Spatial Visualization, $F(2,28)=5.07$, $p<.01$, and Test Position, $F(2,56)=32.60$, $p<.001$. Both the Treatment x Test Position and the Treatment x Spatial Visualization x Test Position interactions reached significance, $F(2,56)=3.53$, $p<.04$ and $F(4,56)=3.48$, $p<.01$, respectively. A graphic

TABLE 2

RAW SCORES

TEST POSITION	LEVEL OF SPATIAL ABILITY	SIMULATION $\bar{X}$	SIMULATION S.D.	TRADITIONAL $\bar{X}$	TRADITIONAL S.D.
Pretest	High	6.3	3.96	5.2	.76
	Medium	4.4	1.24	4.0	.77
	Low	4.6	1.36	3.5	1.84
Immediate Posttest	High	11.1	3.39	3.6	1.71
	Medium	6.3	1.72	5.3	2.36
	Low	4.4	3.32	2.9	2.46
Delayed Posttest	High	10.0	2.97	7.6	2.22
	Medium	8.8	2.07	7.3	2.23
	Low	8.5	2.17	4.2	2.48

representation of the three-way interaction can be found in Figure 2.

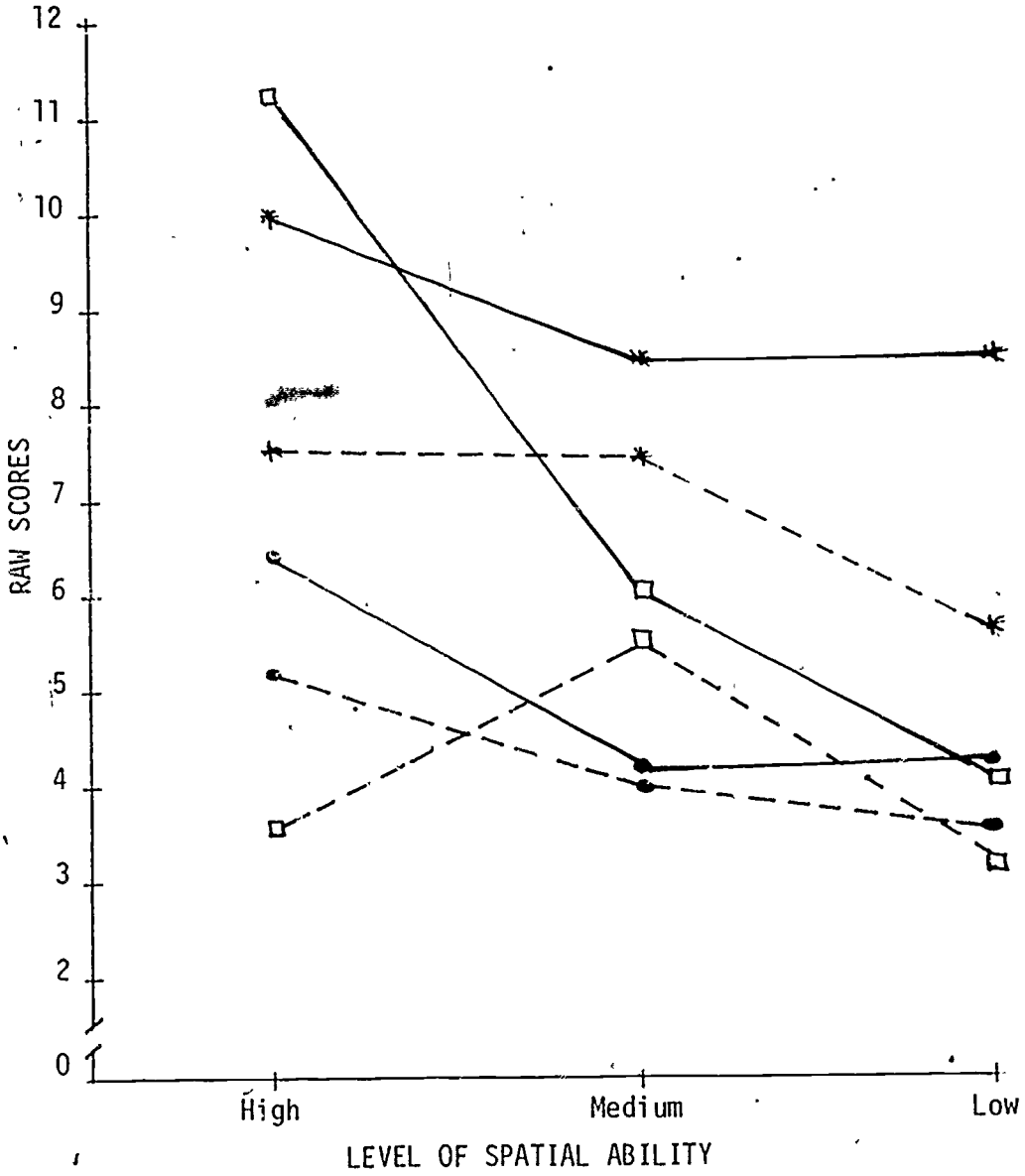
Newman-Keuls analyses on the three-way raw score interaction yielded several interesting results. There were no differential effects for instruction or spatial visualization factors on the pretest or posttest. The only anomaly was the immediate and posttest performance of the high spatial visualization ability groups. The group receiving the traditional instructional treatment performed significantly worse on the immediate test than on the posttest whereas for the group which received the applied Brunerian instructional treatment there was no significant difference between immediate and posttest scores. On both the immediate and delayed posttests, the applied Brunerian group performed significantly better than the traditional group.

Ratio scores. In that subjects were given a 20 minute time limit for completion of the three achievement tests, it was evident from examining the tests that different groups had employed idiosyncratic strategies for producing the maximum number of points. To account for these strategies, ratio scores were calculated by dividing the raw score by the number of problems attempted. Because some subjects would go through the whole test and pick out all of the "easy" questions while others would attempt to complete an entire problem before moving on, the ratio scores provided a more accurate picture of how well the learners understood the entire problem solution.

A 2 Treatment x 3 Spatial Visualization x 3 Test Position ANOVA was performed on the ratio scores for the pretest, immediate test, and posttest. The means and standard deviations are provided in Table 3.

FIGURE 2

ANOVA ON RAW SCORES



Legend

Simulation		Traditional Instruction
——●——	Pretest	- - - - -●- - -
——□——	Immediate Posttest	- - - - -□- - -
——✳——	Delayed Posttest	- - - - -✳- - -

TABLE 3

RATIO SCORES

TEST POSITION	LEVEL OF SPATIAL ACILITY	SIMULATION $\bar{X}$	SIMULATION S.D.	TRADITIONAL $\bar{X}$	TRADITIONAL S.D.
Pretest	High	1.3	.73	1.2	.44
	Medium	1.1	.28	.9	.31
	Low	1.1	.51	.9	.46
Immediate Posttest	High	2.6	.40	1.3	.57
	Medium	1.8	.72	1.8	.61
	Low	1.4	.84	.8	.62
Delayed Posttest	High	2.0	.59	1.7	.33
	Medium	1.8	.26	1.7	.51
	Low	2.1	.42	1.1	.65

All three main effects were statistically significant, Treatment $F(1,28)=10.21$, $p < .003$, Spatial Visualization, $F(2,28)=3.31$, $p < .05$, and Test Position, $F(2,56)=21.99$, $p < .001$. The Spatial Visualization x Test Position interaction was the only interaction to reach significance, $F(4,56)=2.75$, $p < .04$. This interaction is pictured in Figure 3.

In the Newman-Keuls analyses of the ratio scores, the anomalous results which appeared in the raw scores disappeared. For both the high and medium spatial visualization groups there were significant increases ($t(2,13)=3.33$, $p < .05$, $t(2,16)=4.37$, $p < .01$ respectively) from the pretest to the immediate and posttests, which did not differ. The low spatial visualization group, however, again performed no better on the immediate test than on the pretest, but, oddly, showed a significant increase ($t(2,16)=3.38$, $p < .01$) from the immediate test to the posttest.

Number of problems attempted. The suspicion that different response strategies were employed was confirmed by the fact that the ratio score data provided a somewhat different picture than the raw score data. To further examine the strategies the question was asked: Did different groups on different tests attempt to answer a significantly different number of questions? To extend the ratio analysis in answering this question, the number of problems attempted on the pretest, immediate test, and posttest was recorded and an ANOVA performed on these data. Means and standard deviations are presented in Table 4. Test Position was the only main effect that was statistically significant

FIGURE 3

ANOVA ON RATIO SCORES

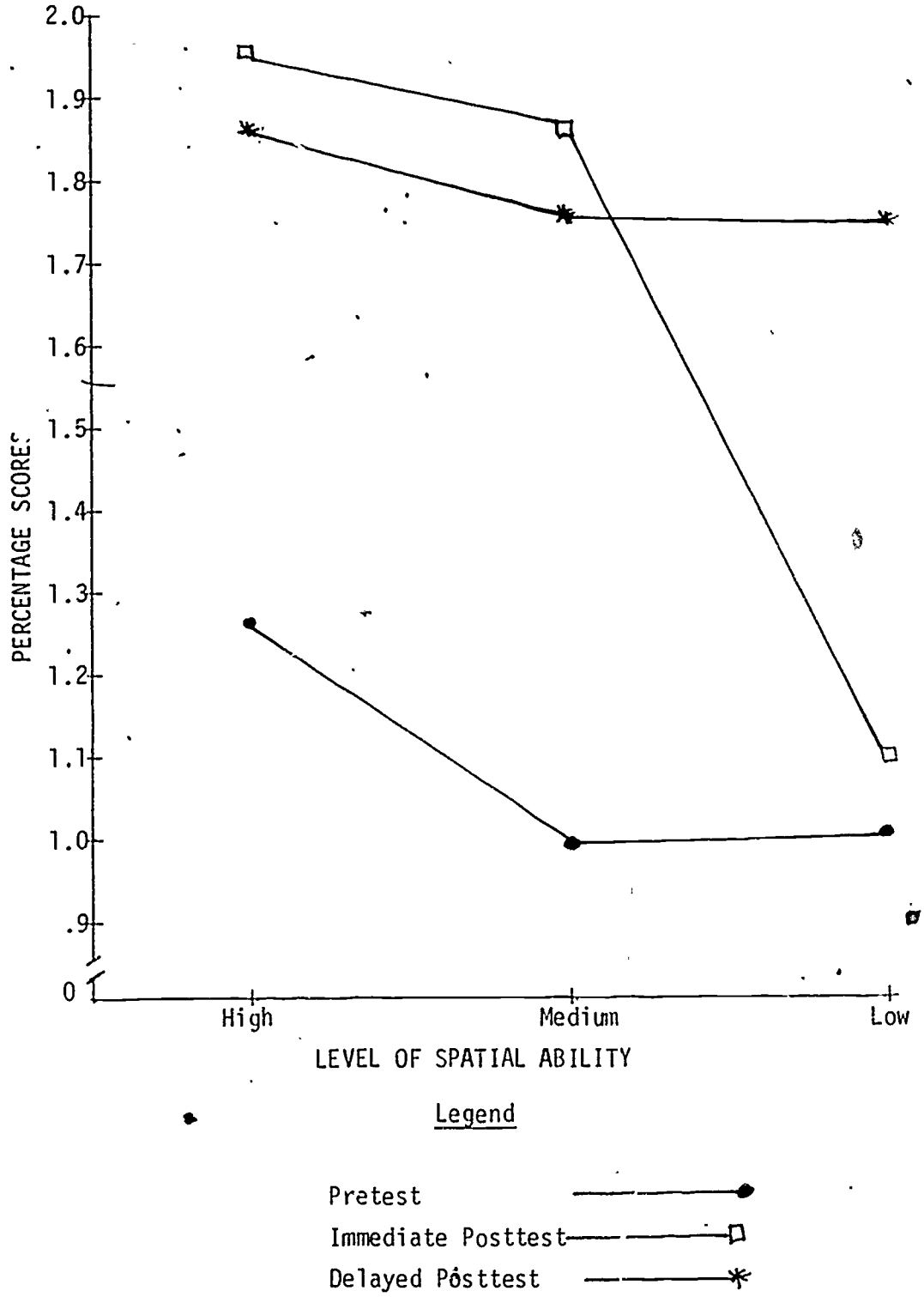


TABLE 4

NUMBER OF PROBLEMS ATTEMPTED

TEST POSITION	LEVEL OF SPATIAL ABILITY	SIMULATION $\bar{X}$	SIMULATION S.D.	TRADITIONAL $\bar{X}$	TRADITIONAL S.D.
Pretest	High	4.6	.89	4.4	.89
	Medium	4.3	.82	4.7	.52
	Low	4.3	.82	4.0	.63
Immediate Posttest	High	4.2	.84	2.8	.45
	Medium	3.7	1.21	3.1	.98
	Low	2.5	1.22	3.5	.84
Delayed Posttest	High	5.0	0.	4.4	.89
	Medium	4.8	.41	4.3	.82
	Low	4.0	.63	4.0	.89

($F(2,56)=25.83$, $p < .001$). There was a significant three-way interaction between Treatment, Spatial Visualization, and Test Position ($F(4,56)=2.72$, $p < .04$). A graphic representation can be found in Figure 4.

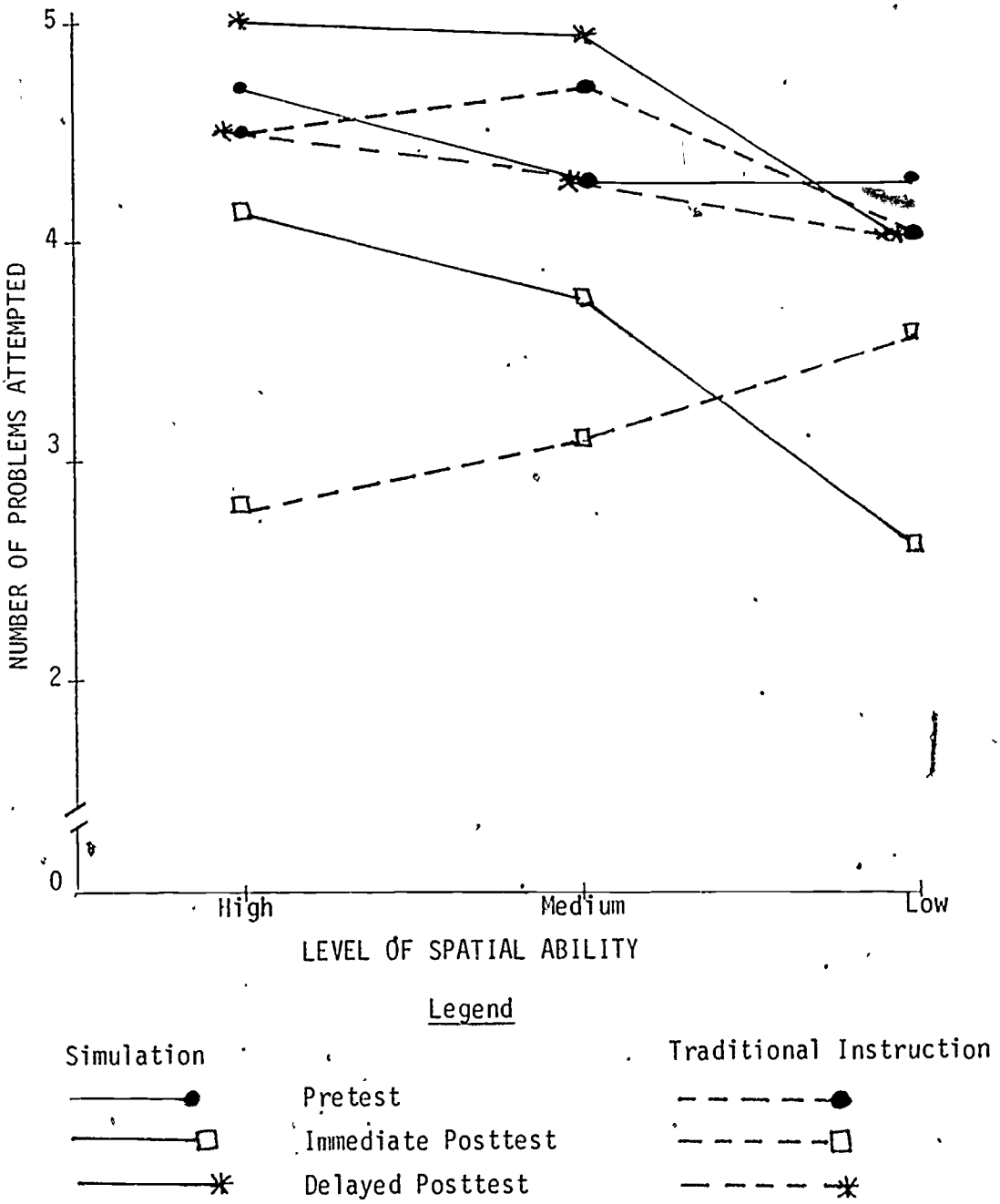
Newman-Keuls analyses showed that all visualization levels in both instructional treatment groups attempted approximately the same number of problems on the pretest and posttest, with all means being greater than four. However, the highly divergent number of problems attempted by almost all groups on the immediate test suggested that they used essentially different response strategies. Looking at the immediate applied Brunerian groups, the means ordered themselves: low visualizers < medium visualizers < high, with only the high visualizers not differing from the pre and delayed test groups. The traditional instructional treatment, however, reacted in reverse, with the high ability group attempting fewer problems than the low group, both of which were equal to the medium group, and only the low group equivalent to the pre and delayed test groups.

Long-Term Effect

In order to assess the long-term effect of the instructional treatment, results from the midterm exam were analyzed. This exam, given five weeks after the posttest, included three of the problems from the question pool from which the pretest, immediate test, and posttest questions were drawn. It also included other problems, multiple-choice questions, and definitions on research design principles and related statistics for a total of 50 points. Test performance was

FIGURE 4

ANOVA ON NUMBER OF PROBLEMS ATTEMPTED



scored by number correct. The results of the midterm can be seen in Table 5. An ANOVA was performed on these data. The applied Brunerian strategy maintained its superiority over time ($F(1,25)=4.29$, $p < .05$). Even though not statistically significant ($F(2,25)=1.37$, $p < .27$), the two-way interaction between spatial visualization ability and instructional treatment is interesting to note due to its obvious qualitative differences. Figure 5 represents it graphically. The hypothesized interaction between spatial visualization and treatment seems to have emerged over time in an important way. The small number of subjects per cell and increased heterogeneity of variance were likely the major factors in the non-significance of the results.

The Newman-Keuls analyses of the midterm exam results again have tentatively confirmed the original hypothesis even after the five week interval. While the simulation and traditional treatment groups did not differ for the high visualizers, the Brunerian approach made a significant impact on both the medium and low groups, whereby the traditional groups performed somewhat less well ($p < .06$). The differences are far more impressive when one notes that the low and medium applied Brunerian groups performed almost 25% better (8 points) than their traditional instructional counterparts.

The block counting test had been administered to assess the affect of the different treatment on spatial ability. A Pearson product moment correlation coefficient was calculated between the combined score on the Dailey and Guilford-Zimmerman tests and the block counting test. An r of .58 was obtained, significant at the .01 level. This confirmed

TABLE 5

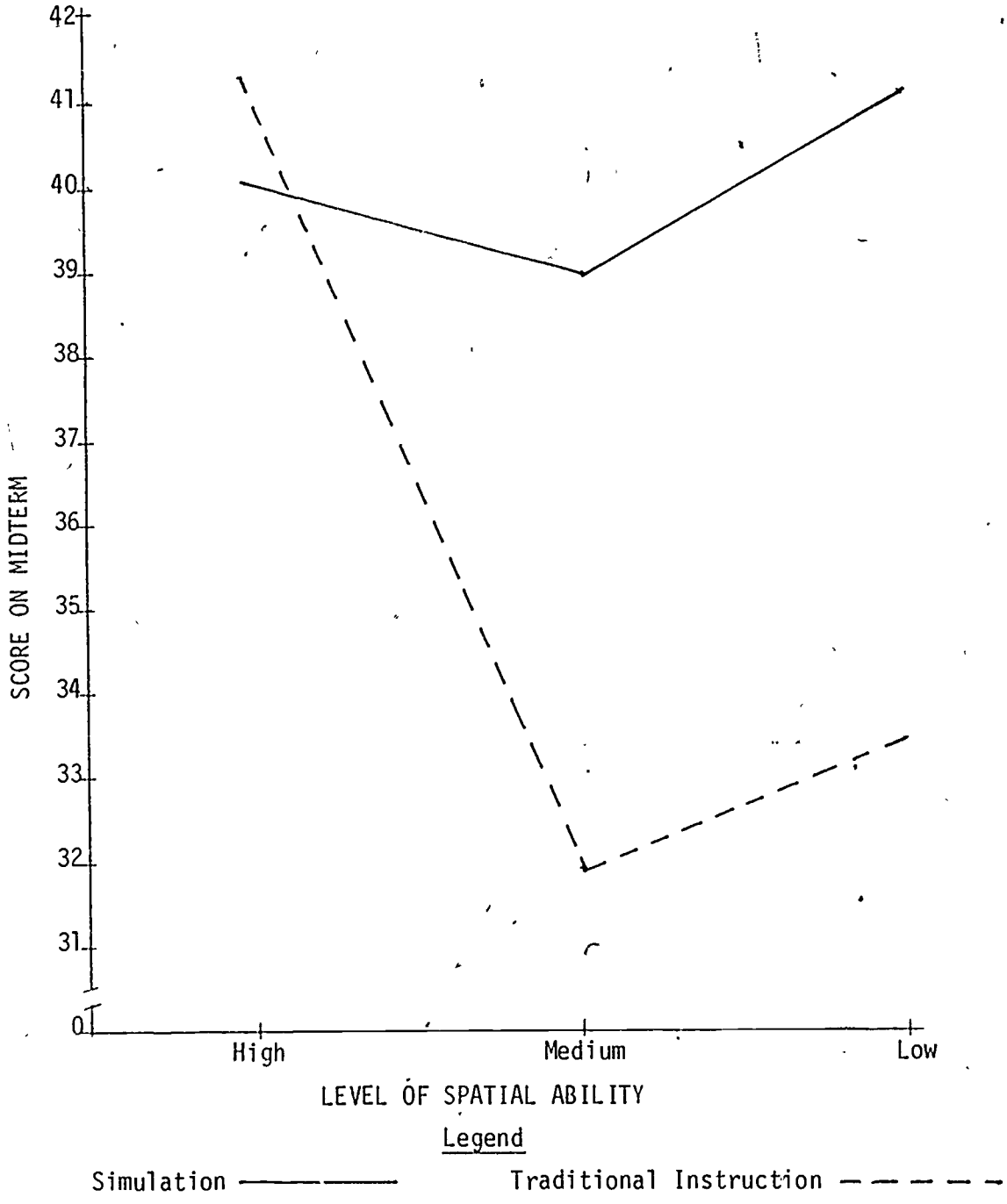
MIDTERM (LONG-TERM DELAYED POSTTEST) SCORES

LEVEL OF SPATIAL ABILITY	SIMULATION		TRADITIONAL	
	$\bar{X}$	S.D.	$\bar{X}$	S.D.
High	40.0	9.12	41.2	6.74
Medium	39.1	2.71	31.9	7.08
Low	41.2	4.19	33.5	8.08

FIGURE 5

ANOVA ON MIDTERM (LONG-TERM DELAYED POSTTEST) SCORES

Graphic representation of non-significant two-way interaction between Spatial Visualization and Instructional Treatment over long-term.



that the block counting test measured essentially the same construct as the two other tests. A t-test was run between the two treatment groups. No difference was found. From this it was inferred that neither set of instructional materials had had an effect on spatial ability per se.

An attempt was made to analyze the solution strategy summary sheets that each subject had completed. Unfortunately, this proved to be impossible as the writing was not sufficiently structure or detailed as to provide a clear indication of the thought processes involved. If this were to be attempted again, it would perhaps be more profitable if the strategy ennunciation were done via individual interview. In this situation, the experimenter could ensure that sufficient detail would be elicited.

Attitude Toward Instructional Materials

Aside from the quantitative aspect of how much more subjects learn from a particular instructional strategy, the question of how subjects react to the material is also of importance. Two of the questionnaire items dealt with overall attitude toward the materials: Q4--Did you find the materials easy to use; and Q5--Did you find the materials enjoyable to use. These items were scored along a five point scale, with one representing a very negative reaction and five a very positive one. The applied Brunerian and traditional groups were compared on their answers to these two items. The means and standard deviations are presented in Table 6. There was no difference at all on the question of enjoyability; with regard to ease of usage of the materials there was only a ma ginally

TABLE 6

ATTITUDE TOWARD MATERIALS

Q4: Did you find the materials easy to use?

	$\overline{X}$	S.D.
Simulation	3.3	1.37
Traditional	2.6	.99

Q5: Did you enjoy using the materials?

	$\overline{X}$	S.D.
Simulation	2.9	1.16
Traditional	2.7	1.31

significant difference in favour of the applied Brunerian group ($t=1.72$, $p < .09$). It should be noted, however, that neither group responded overwhelmingly to their materials ($\bar{X}=2.80$). Since the other items on the questionnaire dealt with more specific aspects of the materials delineating group differences, it was felt that further analyses would not reveal any additional useful information.

CHAPTER FIVE

DISCUSSION AND IMPLICATIONS

The most striking result of the study was the consistent superior performance by the group which had used the applied Brunerian simulation. As well, the expected differential benefit to low spatial ability students as compared to high spatial ability students was evident. Even after a five-week delay, there was still a significant effect for treatment ($p < .05$). This evidence of a long-term, significant (both quantitative and qualitative) difference certainly supported the use of Brunerian theory as a framework for simulation design.

The raw score analyses provided initial quantitative information regarding how the materials were learned under the two treatments. One interesting result was the unexpected behavior of both the high and low spatial visualization groups. Even though one would have expected an increase in performance after instruction, both treatment groups within the low spatial ability section performed virtually the same on the immediate test as on the pretest. The high spatial ability group which received the traditional instructional treatment also performed in this fashion. Only the high spatial ability group which received the applied Brunerian simulation behaved in the expected fashion, i.e. a significant increase from the pretest to the immediate posttest ($p < .01$) and a nonsignificant decrease from the immediate posttest to the delayed posttest (see Figure 2). While the sought-after beneficial effect of the simulation was obtained, this gain was overshadowed by the failure of the traditional instruction to produce learning.

To answer the question of why the instruction appeared to have been ineffective, an analysis of ratio scores was conducted. These scores, calculated by dividing the total number correct by the number of problems attempted, gave a more accurate measure of subject performance, and suggested qualitative differences among groups in the response strategies used. As can be seen in Figure 3, the high and medium spatial ability groups' ratio scores reflected the expected pattern with a significant increase from pretest to immediate posttest. Examination of the number of problems attempted (see Figure 4) provided an explanation for these seemingly conflicting results. There was a significant effect for test position ($p < .001$), with all subjects attempting fewer problems on the immediate posttest than on the pretest or delayed posttest. Apparently the learners felt compelled and able to complete all parts of every problem, having just encountered the instruction. However, because the test had a twenty minute time limit, few learners got beyond the third problem, hence the lower raw scores.

The one exception to this pattern was the low spatial ability group, which still performed only marginally better on the immediate posttest than on the pretest. Although high, medium, and low ability groups attempted approximately the same low number of questions on the immediate posttest, the low ability group had fewer correct answers. At this point, prospects of improved performance for the low ability groups appeared bleak. However, the scores of the low ability group did increase significantly from the immediate to delayed posttest. Moreover, as will be discussed below, the low ability group which received the

simulation performed significantly better ($p < .01$) than the low ability group receiving traditional instruction. Two factors appear to have caused the anomalous behavior of the low spatial ability group on the immediate posttest. First, the low spatial ability groups may have suffered inordinately from the effects of error perseverance (Kulhavy, 1976). That is, the misconceptions which they held regarding the content persisted over the immediate posttest, actually interfering with performance reflective of their acquired knowledge. Second, because this group came particularly ill-prepared to solve these problems, their initial reaction to both the content and the instructional strategy was somewhat confused and negative, although tolerant. During the delay, through other assigned readings not directly related to research design or the problems they were solving, they began to realize the eventual relevance of the materials, and likely lost some of the suspicion and animosity which interfered with their response performance. The affective and subsequent anecdotal data provided further support for this interpretation.

The fact that the medium and low spatial groups maintained their superiority over a five-week delay was strong evidence in support of the effectiveness of the simulation. Unfortunately, this time lapse was accompanied by a natural increase in variance, which, compounded by the small number of subjects, made it unlikely that the two-way interaction would reach significance. However, when one notes the absolute differences involved (the medium and low simulation groups performed an average of 8 points--out of 50--better) the strength of

the trend is obvious. The low and medium ability groups which received the simulation performed better ($p < .06$) than the corresponding groups receiving traditional instruction. The high ability groups, on the other hand, performed equally well regardless of the treatment received. This confirmed the special benefit that the applied Brunerian simulation had for the lower spatial ability students.

Affective Effects

There was no difference in affective attitudes toward the instruction between the two treatment groups. This finding is consistent with previous research. While disappointing in the sense that a more positive attitude toward simulations would further reinforce their utility, this eliminated the possibility that motivation had a significant effect on subjects' performance. One contributing factor to the generally neutral response of both treatment groups was the timing of the study. Because it occurred at the beginning of term, many students were unable to perceive the relevance of the materials to the course, despite assurances that they were. It had, however, been decided that no time would be spent in trying to change the students' attitude to the task; it was more important that all subjects had basically the same level of prior knowledge. Furthermore, since the affective response was uniformly lukewarm, a potential confounding variable was eliminated.

Sex Differences

As reported in Chapter Four, there was no significant difference

between the sexes in performance . the spatial ability tests. This is in contrast with past studies which have reported striking differences in spatial visualization ability according to sex. Such results have been widely used, post hoc ergo propter hoc, to support the theory that such differences in abilities were innate. This strong cultural bias has had effects on many aspects of life ranging from stereotyped sex roles to vocational training. That traditional tests of spatial visualization ability in this study and others (Elmore & Vasu, 1980; Fennema & Sherman, 1977) now show no significant sex differences probably reflects changes in the sociocultural environment. Thus, given the materials tested here, differentiating instructional materials and methods on the basis of presumed sex differences is likely to be nonproductive.

Isolating Task Aptitudes

Spatial ability was obviously an important ability in learning research design principles. This finding confirmed work done by Elmore and Vasu (1980) and Kulhavy et al (1977) and has important implications for instructional design. Instructional materials for research design should take into account the importance of spatial visualization and provide compensatory instruction for students weak in it.

It should also be recognized that the usefulness of identifying the primary aptitude(s) involved in a learning task is not limited to the learning of research design principles. The development of

instruction for other learning tasks will also benefit from such a process. While the ATI model is useful for research in isolating significant aptitudes, it does not follow that it is equally useful as an application model in the way that Cronbach and Snow (1977) talk about assignment to different teaching methods based on the point of interaction. A task-oriented approach to designing instructional materials can be more efficient than an ATI approach; therefore, the first step for instructional design should be the isolation of the significant aptitude(s) involved.

In summary, this study has suggested the apparent usefulness of Brunerian learning theory for instructional design. When combined with the medium of simulation, Brunerian theory can provide not only a structure for design, but also a theoretical rationale for materials development. As the simulation used in this thesis managed to help low ability students as well as or more than, relatively speaking, high ability students, there seems to be potential for universal application of an instructional design to a particular task rather than aptitude-based assignment of students to instructional materials.

The evidence from one study is clearly not sufficient to make strong generalizations about the state of the art or its future direction. As one proponent of inductive reasoning stated, "It is a capital mistake to theorize in advance of the facts." (Holmes in Doyle, 1904) The "facts" which this study uncovered nonetheless appear to hold great promise for both theory building and application; it seems that further detective work along this same line of reasoning would prove useful.

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